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and Cooling in Integrated Urban
and Industrial Energy Systems

Conference Proceedings






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DISTRICT COOLING VISION FOR VIENNA: TOWARDS A CLIMATE NEUTRAL URBAN FUTURE

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SUMMARY

The "District Cooling Network" outlines Vienna's strategic vision to become the District Cooling Capital of Europe. By integrating renewable energy, river water, waste heat, and storage technologies, the initiative aims to make district cooling a daily reality for all residents in the Inner-city area. With a projected connection capacity of 230 MW by 2025, the network will serve both commercial and historic buildings. Key technologies include ice storage systems, absorbers, centrifugal chillers, and heat pumps using natural refrigerants. These innovations contribute to energy efficiency and the decarbonization of Vienna.
Keywords: District Cooling, Vienna, Renewable Energy, Ice Storage, Heat Pumps, Decarbonization

INTRODUCTION

Vienna is positioning itself as a European leader in sustainable urban cooling. The city's district cooling strategy emphasizes climate neutrality, energy efficiency, and integration with existing infrastructure. It is presented the vision, technological components, and implementation strategy of Vienna's district cooling network. Using river water cooling technology, excess heat from the overheated core area of the city can be efficiently discharged via the Danube Canal. This helps reduce urban heat islands and improves the local microclimate.

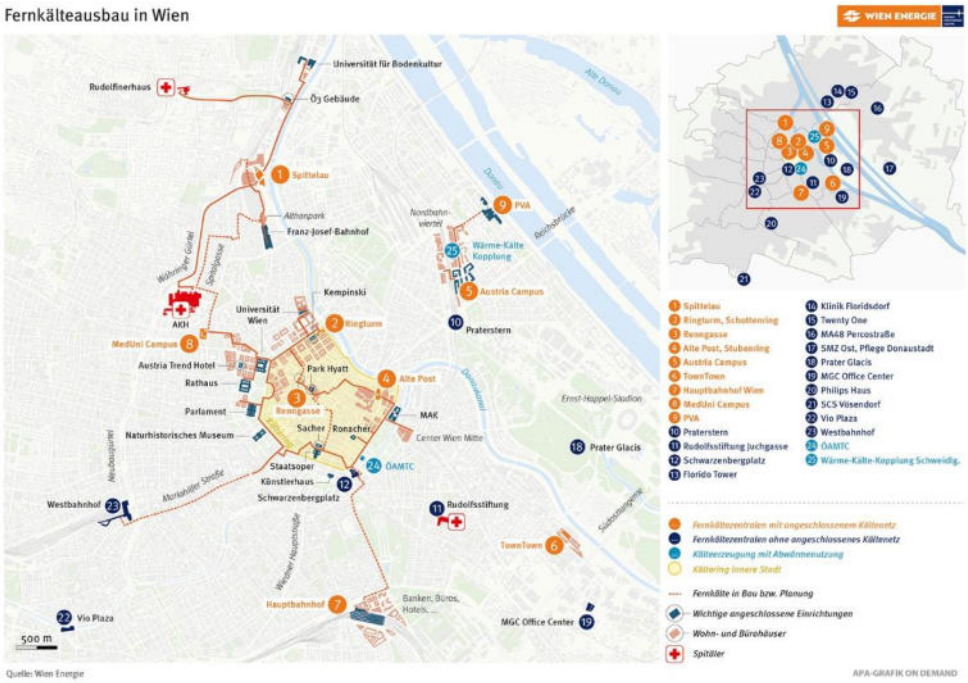
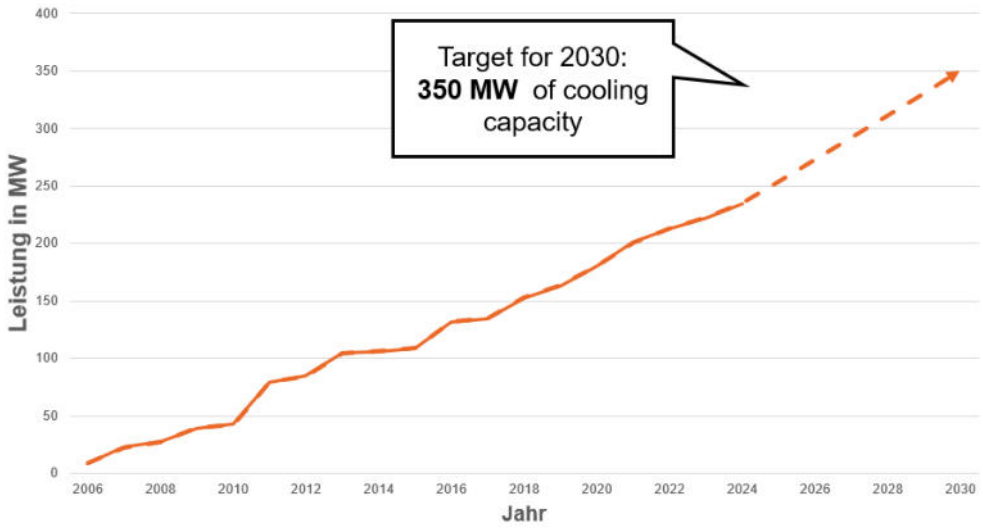


Fig. 1: District Cooling Network Vienna

STRATEGIC DEVELOPMENT

The development strategy focuses on three pillars: customer potential, production facilities, and main hydraulics. By 2025, the network will expand to multiple systems with a total customer connection capacity of approximately more than 230 MW. The goal for 2030 is to expand to 350 MW and establish a comprehensive network in the city centre. The system is designed to serve both modern commercial buildings and historic structures, preserving architectural heritage while meeting contemporary cooling demands.

Table 1: Connected load



TECHNICAL INNOVATIONS

A new element is the use of ice storage systems, which enhance energy efficiency by storing cooling energy during the night and discharging it at day. The MedUNI cooling plant exemplifies this approach, combining absorbers, centrifugal chillers, ice storage, and waste heat recovery. When outdoor temperatures exceed 12 °C, the absorber is prioritized and operated using waste heat from the district heating network. In winter, a screw compressor with a heat pump provides cooling and low-temperature heat. In summer, centrifugal chillers handle peak loads.

The Oberlaa heating network demonstrates the use of natural refrigerants, where thermal water and ammonia-based heat pumps supply 1,900 households.

CONCLUSION

Vienna's district cooling initiative showcases how efficient technologies, and natural refrigerants can support urban decarbonization. The integration of renewable sources, advanced storage, and heat pump systems positions Vienna as a model for sustainable urban cooling in Europe.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

- Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage.
- Future District Heating and Cooling Solutions
- Circular Economy Strategies for the Energy Transition

TRANSFORMATION OF DISTRICT HEATING SUPPLY TOWARDS CLIMATE NEUTRALITY IN GERMANY

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SUMMARY

To transform district heating networks towards climate neutrality, electric heat generators, renewable heat sources and unavoidable waste heat will have to cover the increasing demand for district heating in future. As part of a two-stage approach consisting of a GIS analysis of the spatial distribution of district heating demand and the potential for renewable district heating in Germany (stage 1) and a dispatch optimisation for electricity and district heating generation (stage 2), key figures on the energy source mix, CO_2 emissions, technology-specific operating hours and costs of the district heating supply in different districts are derived. Districts with a large potential of unavoidable waste heat or renewable energies can provide district heating at lower costs and lower CO_2 emissions than other districts. Electric district heating generators primarily reduce costs and serve as a flexibility option for the electricity system.
Keywords: district heating, transformation towards climate neutrality, spatial analysis and sector coupling

INTRODUCTION

The transformation of district heating supply towards climate neutrality poses different challenges for individual district heating networks. While large-scale power plants with combined heat and power generation and based on fossil fuels have been the main source of district heating in Germany in the past, renewable heat sources and unavoidable waste heat will have to meet the increasing demand for district heating in the future.

Coal-fired power plants are often replaced by smaller natural gas-fired power plants, which must be operated with hydrogen or CCS in the long term in order to be climate-neutral. However, these are comparatively expensive district heating generation technologies. It is therefore important to integrate unavoidable waste heat, geothermal energy and electrical heat generators into the district heating networks. However, renewable district heat potentials are distributed differently in Germany.

METHOD

This work is based on a two-stage approach: a GIS analysis for the spatial distribution of district heating demand and renewable district heating potentials in Germany (stage 1) as well as a dispatch optimisation for power plants, storages and flexibility options in the European power network and for district heating generation in district heating areas in Germany (stage 2).

In the GIS analysis, various publicly accessible data sources on current and future district heating network areas, such as the 2022 census database[1] or the sEEnergies open data hub[2], are combined with each other. Based on these district heating areas, the renewable district heat potentials from geothermal energy, solar thermal energy and unavoidable waste heat, as well as conventional powerplants and waste incineration plants located in close proximity were determined and allocated to the 400 districts in Germany. For districts that do not have a sufficient

[1] https://ergebnisse.zensus2022.de/datenbank/online/
[2] https://s-eenergies-open-data-euf.hub.arcgis.com/

renewable district heat potential, electric heat generators and boilers with synthetic or biogenic fuels are being added taking into account certain limits. As a result, each district contains an individual mix of generation technologies to meet its district heating demand.

The use of the various generation technologies for electricity in the European power network and for district heating in district heating areas in Germany is modelled using the Öko-Institut's PowerFlex[3] electricity market model. The marginal costs of CHP plants and electrical heat generators vary endogenously depending on the resulting electricity prices. The results are district-specific key figures on the energy source mix, CO_2 emissions, technology-specific operating hours and costs of the district heating supply.

SCENARIO FRAMEWORK

The project specific scenario framework used in this evaluation is mainly based on two current target scenarios towards climate neutrality. The scenario pathway B from the German Network Development Plan Electricity 2037 / 20245 (Bundesnetzagentur 2025) is largely congruent with the current system development strategy in Germany of the Federal Ministry for Economic Affairs and Energy. Direct electrification is a key transformation strategy and the expansion path for renewable energies under the German Renewable Energies Act (EEG) is adhered to. In addition, the district heating demand and the energy source-specific potential for district heating generation are based on the scenarios “Climate-neutral Germany” from Agora Think Tanks (2024) and “Heating networks: climate-neutral, economical and affordable” from Agora Energiewende, Prognos, GEF (2024). The demand for district heating in buildings will roughly double by 2045 compared to today, from 65 TWh to 135 TWh.

RESULTS AND CONCLUSIONS

The spatial distribution of district heating demand in buildings is primarily focussed on urban districts and metropolitan regions. The five cities of Berlin, Hamburg, Munich, Cologne and Essen alone account for 25% of district heating demand in Germany in the scenario year 2045. District heating is becoming the dominant heating technology in buildings there (figure 1, left map). In the cities of Hamburg, Cologne and Munich in particular, but also in Mannheim, Essen, Frankfurt and other cities, the demand for district heating correlates very well with the installed thermal capacity for district heat generation of waste incineration plants (figure 1, right map).

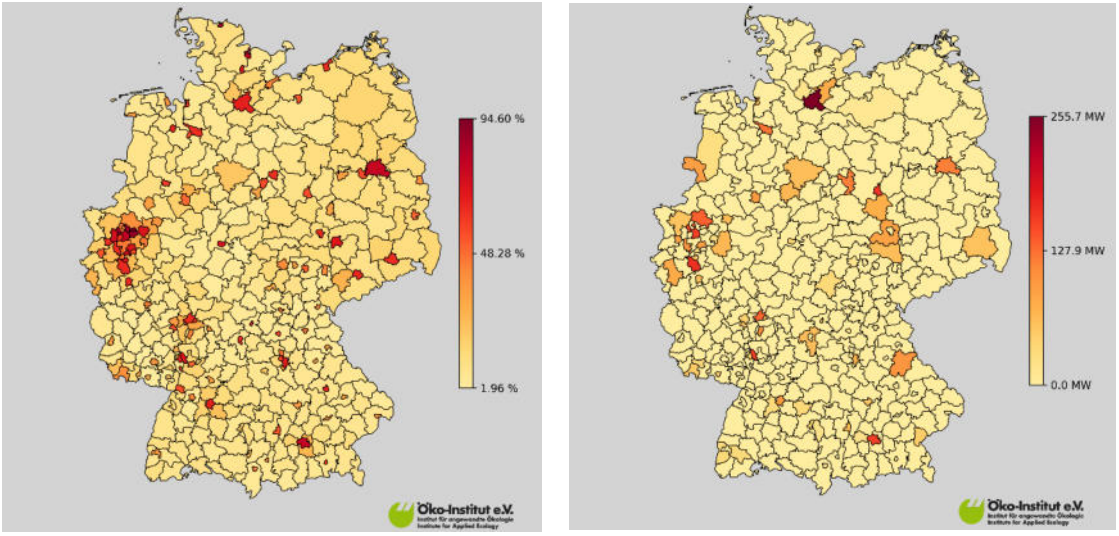


Fig. 1: Share of district heating supply for residential buildings (left) and installed thermal capacity for district heat

[3] https://openenergyplatform.org/factsheets/models/120/

generation of waste incineration plants (right) in the scenario year 2045

The distribution of gas-fired power plants with CHP is also based on the demand centres. The geothermal potential in Germany is limited to the Molasse Basin in southern Bavaria, the Upper Rhine Graben and the North German Plain.

The disptatch optimisation will be completed by the end of 2025. Initial results show that districts with a large potential of unavoidable waste heat, such as Hamburg (industrial area at the port) or Frankfurt (data centres), or renewable energies, such as Munich (geothermal energy), can provide district heating at lower costs and lower CO_2 emissions than other districts. If districts have to resort to the comparatively expensive energy sources of hydrogen or synthetic fuels due to insufficient renewable heating potential, the district heating supply becomes correspondingly expensive. Electric district heating generators mainly reduce costs and act as a flexibility option for the electricity system.

ACKNOWLEDGMENTS

This work was carried out as part of the project “Dashboard heat transition - system analysis and visualization of regional effects” (2023 – 2026), which is funded by the Federal Ministry for Economic Affairs and Energy based on a resolution of the German Bundestag.

REFERENCES

Agora Energiewende, Prognos, GEF (2024): Heating networks: climate-neutral, economical and affordable. https://www.agora-energiewende.de/publikationen/waermenetze-klimaneutral-wirtschaftlich-und-bezahlbar

Agora Think Tanks (2024): Klimaneutrales Deutschland. Von der Zielsetzung zur Umsetzung. https://www.agora-energiewende.org/publications/climate-neutral-germany

Bundesnetzagentur (2025): Genehmigung des Szenariorahmens für den Netzentwicklungsplan Strom 2025-2037/2045. https://www.netzentwicklungsplan.de/en

Fallahnejad, M., Kranzl, L., Haas, R., Hummel, M., Müller, A., Sánchez García, L., Persson, U., (2024), District heating potential in the EU-27: Evaluating the impacts of heat demand reduction and market share growth, Applied Energy, Volume 353, Part B, 2024, 122154, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2023.122154.

Manz, P., Billerbeck, A., Kök, A., Fallahnejad, M., Fleiter, T., Kranzl, L., Braungardt, S., Eichhammer, W. (2024), Spatial analysis of renewable and excess heat potentials for climate-neutral district heating in Europe, Renewable Energy, Volume 224, 2024, 120111, ISSN 0960-1481, https://doi.org/10.1016/j.renene.2024.120111.

CONFERENCE TOPIC

1.04. Coupling of Energy Sectors
1.08. Future District Heating and Cooling Solutions
2.08. Spatial Energy Planning with Emphasis on Renewable Energies

The importance of Asset management of District Heating Pipes for the implementation of climate goals in Europe

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SUMMARY

The aim of the asset management of district heating pipes is to create the financial framework for a reliable, affordable and ecological heat supply in a district heating system. Today, estimates based on available statistical data suggest that over 19,000 heating networks with a total length trace of over 199,000 km supply heat to over 80 million inhabitants in the EU (Priel E. et al 2025). With the 'European Green Deal' and the EU 'Fit-for-55' legislative package, the European Union has described its climate targets and established the political framework for achieving them through the Renewable Energy Directive (RED III, 2023), the Energy Performance of Buildings Directive (EPBD, 2024) and Energy Efficiency Directive (EED, 2023). Existing district heating systems, their transformation and expansion as well as building new district heating systems are essential for the achievement of the European climate targets. To this end, network operators require reliable asset management tools for implementing the EU climate goals. This paper presents the factors influencing the service life of different pipe systems and approaches for improving asset management simulations based on ongoing national and international research.

INTRODUCTION

In district heating systems, the quality and security of supply depend directly on the functionality of the heating network (AGFW FW 113, 2017). In Europe today, approximately 19,000 district heating networks with a total route length of approximately 199,000 kilometres supply heat to around 80 million inhabitants (Priel E. et al 2025). These heating networks have developed as infrastructure in urban areas under various technical, ecological and economic conditions. As a result, every heating network in Europe has its own individual characteristics, which are reflected in the network structure with the corresponding heat generation plants, the technical operating parameters (e.g. temperature and pressure) and the pipe systems installed. In addition to suitable maintenance strategies for the pipe systems used, asset management analyses of the heating network form the basis for network expansion strategies and budget planning by heating network operators to maintain security of supply (AGFW FW 114, 2013).
The European Union's 'Fit for 55' legislative package aims to reduce greenhouse gas emissions by at least 55% in 2030 compared to 1990 levels and to achieve full climate neutrality by 2050 (Fit for 55, 2022). For existing

and new district heating systems, the EU directives EED (2023), EPBD (2024) and REDIII (2023) contain key targets for future heat generation and performance of district heating systems, as well as for reducing the final energy consumption of buildings supplied by district heating. To meet European targets, utility companies will have to invest heavily in tapping local renewable energy potential and existing waste heat, as well as in maintaining, adapting and expanding their heating networks. For existing district heating systems, precise knowledge of the condition and service life of the existing pipe systems is particularly important, as the existing infrastructure forms the basis for the targets, strategies for their implementation and the necessary financial resources for the development of an individual transformation path.
Based on the fundamentals and methods of system asset management of district heating pipes, this paper presents the factors influencing the service life of different pipe systems and approaches for improving asset management simulations based on ongoing national (SAM-FW, 2025) and international (IEA DHC TS6, 2025) research projects in the context of European climate targets.

REFERENCES

AGFW FW 113, (2017), Quality of supply in district heating. Frankfurt am Main, AGFW. (in German)
AGFW FW 114, (2013), Strategies for maintenance and planning of rehabilitation. Frankfurt am Main, AGFW.
Energy Performance of Buildings Directive, (2024), https://eur-lex.europa.eu/eli/dir/2024/1275/oj/eng
Energy Efficiency Directive (EED), (2023), https://eur-lex.europa.eu/eli/dir/2023/1791/oj/eng
Fit-for-55, (2022) https://www.consilium.europa.eu/en/policies/fit-for-55/
IEA DHC TS6, (2025), project webpage, https://www.iea-dhc.org/the-research/2021-2025-annex-ts6
Piel, E., Mata, C., Maréchal A. et al., (2025), DHC Market Outlook 2025 – Executive Summary, Euroheat & Power, Brussels, Belgium (https://www.euroheat.org/data-insights/outlooks/dhc-market-outlook-2025)
SAM-FW, (2025), project webpage, https://www.agfw.de/forschung/sam-fw
Renewable Energy Directive (RED III), (2023), https://eur-lex.europa.eu/eli/dir/2023/2413/oj/eng

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CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

- Future District Heating and Cooling Solutions
- Sustainable Renovation and Energy Retrofits
- Transform Cities: Holistic Approaches to Sustainable Urban Energy

Support Schemes for Implementation in Buildings, Industry, Districts, Cities and Regions
Financing and Business Models
Life Cycle Assessment
Spatial Energy Planning with Emphasis on Renewable Energies

A COMPARATIVE TECHNO-ECONOMIC ASSESSMENT OF SEASONAL THERMAL ENERGY STORAGE FOR DECARBONIZED DISTRICT HEATING NETWORKS

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SUMMARY

This study evaluates the techno-economic feasibility of integrating seasonal thermal energy storage systems (STES) into existing district heating and cooling networks (DHCN). It compares underground STES options (pit, aquifer, and boreholes) with conventional water tank storage to determine the favourable configurations. High-temperature solar thermal collectors are included on the source side to assess the potential for higher renewable shares under multiple integration scenarios. All alternatives are benchmarked against a business-as-usual case, considering technical dispatch performance and long-term economic indicators. Environmental performance is analysed by mapping CO_2 emissions under varying carbon taxes. A sensitivity analysis explores the relative impact of heat pump and electric boiler capacities and thermal storage sizing. The results provide insights into long-term system development pathways and offer practical recommendations for policymakers, energy planners, and industry professionals to facilitate the transition toward sustainable district heating and cooling networks.
Keywords: seasonal thermal energy storage, District heating and cooling network, Energy system modelling, Performance comparison.

INTRODUCTION

To achieve global climate targets and a carbon-neutral economy, a transition towards decarbonizing the energy sector, with a particular focus on the heating and cooling sector, is crucial (Gao, 2024). In 2019, the heating sector accounted for about half of total end-use energy consumption and was responsible for approximately 40% of CO_2 emissions. According to IEA, despite the increase in renewable energy usage, the intermittent nature of these sources results in seasonal and daily mismatches between renewable heat generation and demand, highlighting the need for a diverse mix of energy sources (Hansen *et al.*, 2016). To facilitate the integration of renewables and ensure their optimal utilization, energy storages play an integral part by reducing reliance on emission-intensive fossil fuels for both electricity generation and thermal applications. As a potential solution, diurnal and seasonal storage capabilities offer added value to the energy grid by shifting renewable energy generation to better match the heating demand (Akindipe *et al.*, 2024). Numerous studies introduce heat savings as a game changer in the future of decarbonized energy systems. However, these technologies require large energy storage capacities, raising the key question of how much of this heat saving is truly feasible and how it varies depending on the characteristics of the local energy system (Hansen *et al.*, 2016). To address these challenges, the dispatch of the proposed system is optimized by means of a MILP algorithm that accounts for key technical and operational inputs. The algorithm is implemented in Pyomo, a Python-based optimization modelling framework, and solved with the CBC solver (Ehrhart *et al.*, 1975). Following a bottom-up modelling approach for economic evaluation, based on specific costs and data gathered from literature, the model has been developed to describe and analyse the economic performance of the proposed systems. The economic KPIs considered are OPEX relative to the business-as-usual (BAU) scenario and the nominal levelized cost of heat (LCOH). In particular, the objective of the dispatch algorithm, shown in Eq. (1), is to minimize operational costs associated with auxiliary power-to-heat technologies and fossil-fuel burning boilers, while also accounting for benefits of reusing industrial waste heat and integrating storage through relevant system constraints (Trevisan, Buchbjerg and Guedez, 2022).

$$\bar{F} = \min\left\{\sum_{t=0}^{n}[(p_{el}(t).\sum_a P_a(t)) + \left((p_f(t).\sum_B Q_B(t)\right)\right]\right\} \quad \text{(eq. 1)}$$

Preliminary results include the BAU case compared with scenarios that implement water tank energy storage (WTES) and pit thermal energy storage (PTES) within the district heating system. After optimizing the operating capacity of power-to-heat technologies (electric boiler and heat pump) in BAU case, the corresponding annual energy mix of the energy system, as well as the electricity consumption by power-to-heat technologies, were calculated. The preliminary results are shown on Fig. 1.

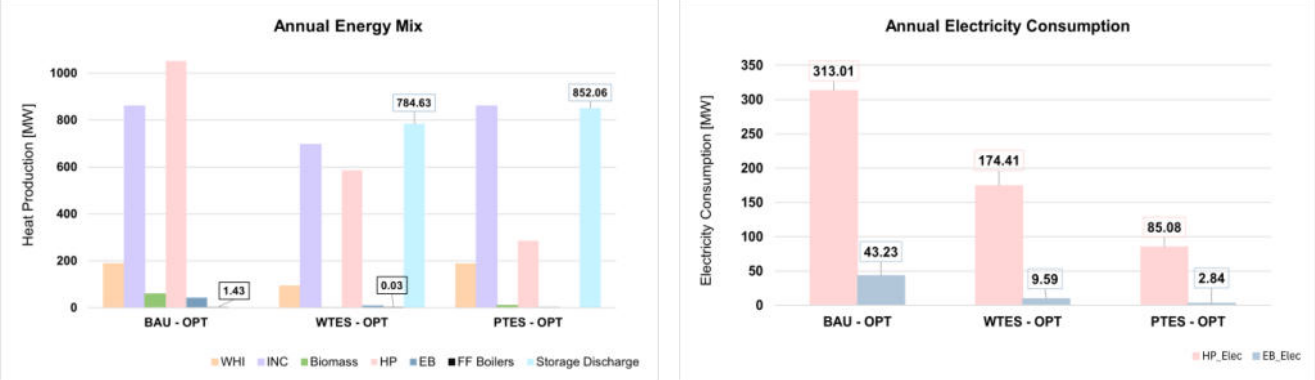


Fig. 1: Annual energy mix of the energy system (a) and electricity consumption of Power-to-Heat technologies (b) under optimal dispatch for the BAU, PTES and WTES scenarios.

As shown in Fig.1(a), integrating storage into the energy system reduces or eliminates reliance on fossil-fuel boilers. Therefore, the system charges storage during low electricity price hours and discharges it when prices peak. With the larger capacities provided by underground thermal storage (PTES), the operating hours of heat pump and electric boilers decrease, as the system prioritizes storage to reduce operational costs (Fig.1 (b)). The next step in this study is to evaluate the operational and economic performance of the system when also considering additional types of underground thermal storage and increasing the share of renewables in district heating and cooling networks. Furthermore, by combining detailed dispatch modelling with techno-economic and emissions assessment, this work aims to bridge system optimization and policy relevance in the context of future low-carbon heating transitions.

REFERENCES

Akindipe, D. et al. (2024) Techno-Economic Analysis and Market Potential of Geological Thermal Energy Storage (GeoTES) Charged With Solar Thermal and Heat Pumps. NREL/TP--5700-91225, 2474842, MainId:93003, p. NREL/TP--5700-91225, 2474842, MainId:93003. Available at: https://doi.org/10.2172/2474842.

Ehrhart, I.C. et al. (1975) "Coronary vascular and myocardial responses to carotid body stimulation in the dog," The American Journal of Physiology, 229(3), pp. 754–760. Available at: https://doi.org/10.1152/ajplegacy.1975.229.3.754.

Gao, M. (2024) "Large Scale Heat Storage for Solar District Heating."

Hansen, K. et al. (2016) "Heat Roadmap Europe: Identifying the balance between saving heat and supplying heat," Energy, 115, pp. 1663–1671. Available at: https://doi.org/10.1016/j.energy.2016.06.033.

Trevisan, S., Buchbjerg, B. and Guedez, R. (2022) "Power-to-heat for the industrial sector: Techno-economic assessment of a molten salt-based solution," Energy Conversion and Management, 272, p. 116362. Available at: https://doi.org/10.1016/j.enconman.2022.116362.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
1.08: Future District Heating and Cooling Solutions
1.13: Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

BI-GENERATION IN DATA CENTRES: WASTE HEAT RECOVERY FOR DISTRICT HEATING USING HIGH-TEMPERATURE HEAT PUMPS

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SUMMARY

The rapid growth of data centres worldwide has created a dual challenge: ensuring reliable cooling for IT equipment while reducing the environmental footprint of energy-intensive operations. Traditionally, Power Usage Effectiveness (PUE) has served as the primary efficiency metric, yet it fails to capture the sustainability benefits of energy reuse. To address this limitation, *The Green Grid* introduced the Energy Reuse Factor (ERF) and the derived Energy Reuse Effectiveness (ERE), which incorporate the share of exported useful energy—such as waste heat delivered to district heating systems—into performance assessment. This paper explores the role of bi-generation, where cooling and heating are provided simultaneously, and quantifies the achievable district heating supply temperatures and recovery potentials when employing high-temperature (lift) heat pumps.

Keywords: Power Usage Effectiveness (PUE), Energy Reuse Effectiveness (ERE); Exergy Analysis; Energy Reuse Factor (ERF), Coefficient of Performance (COP), Coefficient of Performance for Bi-Generation (COP_com)

INTRODUCTION

Data centres already account for over 2% of global electricity consumption (Oró et al., 2015). Their integration into future sustainable energy systems depends not only on reducing energy demand but also on valorizing waste heat (Huang et al., 2020). While PUE (The Green Grid, 2010) provides a measure of internal efficiency, it ignores external benefits of heat recovery. By introducing ERF as the ratio of reused energy to total energy consumption, and ERE, as shown in fig. 1, data centres can be benchmarked in terms of both efficiency and system integration. However, the technical feasibility of energy reuse hinges on the ability to achieve sufficiently high supply temperatures. This is where bi-generation and heat pump technologies become central.

METHODOLOGY

Our analysis shows that with standard chillers, achievable condenser temperatures may already reach 40–50 °C, sufficient for low-temperature heating networks. However, this comes at the cost of reduced EER (i.e., increased power input per unit cooling), which negatively influences PUE.

When high-temperature lift heat pumps are integrated, more than 80% of the total waste heat can be recovered and upgraded to district heating supply levels exceeding 70–80 °C. In this case:

- ERF rises sharply with increasing COP, as more useful energy is exported per unit total energy input.
- ERE decreases with higher COP, indicating improved effective efficiency when reuse is accounted for.
- The overall PUE remains dominated by IT and auxiliary loads but increases slightly with added heat-pump consumption.

It is important to stress that while heat recovery improves ERF and ERE, the PUE must remain below a certain threshold (typically <1.3–1.5 in modern facilities) to ensure that core efficiency is not sacrificed for the sake of high-grade heat recovery. Maintaining a balance between low PUE and high ERF is therefore essential to maximize both internal efficiency and external energy system benefits, compared to Wang et al. (2024).

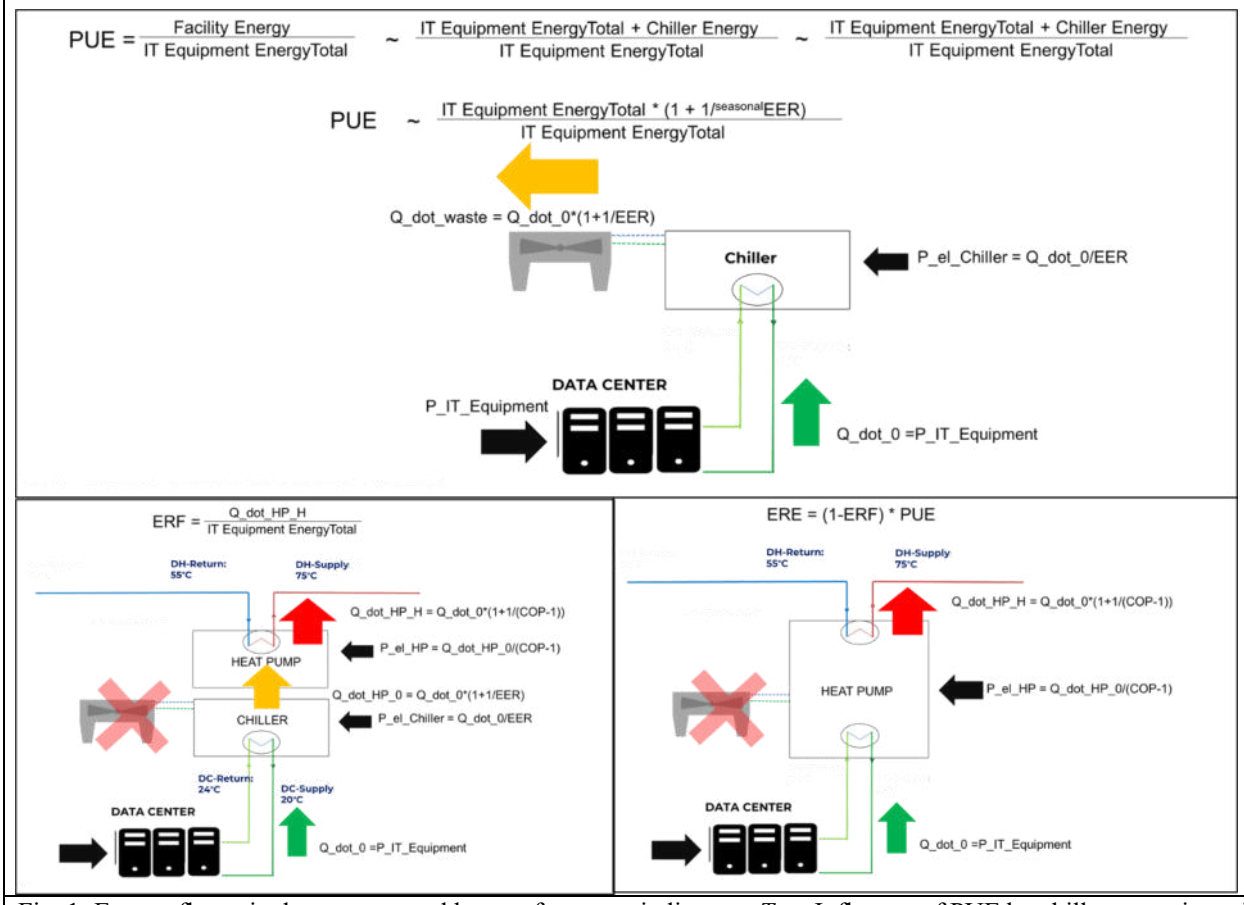


Fig. 1: Energy fluxes in data centres and key performance indicators. *Top*: Influence of PUE by chiller operation without waste heat utilization. *Bottom left*: Influence on ERF when waste heat is recovered via a heat pump connected to the chiller. *Bottom right*: Influence on ERE using high-temperature lift heat pumps in bi-generation, providing simultaneous cooling and heating.

CONCLUSION

The integration of high-temperature lift heat pumps into data centres enables bi-generation, providing simultaneous cooling for IT loads and heating for district energy systems. In this configuration, even supply temperatures of 120 °C and higher can be achieved efficiently. This development is supported by the trend that the required cooling temperature in data centres is rising—from approximately 6 °C in traditional air-cooled systems to 20 °C and above in liquid-cooled facilities—which significantly improves the thermodynamic conditions for heat recovery. Our calculations demonstrate that supply temperatures suitable for both modern and legacy district heating grids can be reached, with more than 80% of waste heat recoverable. Although conventional chillers can provide higher condenser temperatures, this is accompanied by efficiency penalties due to lower EER values. By contrast, high-temperature heat pumps represent the most effective pathway to maximize ERF, reduce ERE, and enhance the role of data centres as active contributors to sustainable and decarbonized energy systems. Importantly, PUE must be monitored and maintained within acceptable limits to ensure that improved heat recovery does not compromise the fundamental efficiency of data centre operations.

REFERENCES

The Green Grid. (2010). *ERE: A Metric for Measuring the Benefit of Reuse Energy from a Data Center*.

Oró, E., Depoorter, V., García, A., & Salom, J. (2015). Energy efficiency and renewable energy integration in data centres: Strategies and modelling review. *Renewable and Sustainable Energy Reviews*, 42, 429–445.

Huang, P., Copertaro, B., & Zhang, X. (2020). Datacentres as prosumers in district energy systems: Renewable energy integration and waste heat reuse for district heating. *Applied Energy*, 258, 114109.

Wang, Y., Han, Y., Shen, J., et al. (2024). Data center integrated energy system for sustainability: Generalization, approaches, methods, techniques, and future perspectives. *The Innovation: Energy*, 1(1), 100014.

CONFERENCE TOPIC

1.08 Future District Heating and Cooling Solutions or 1.04. Coupling Energy Sectors of 1.06

HYDROGEN-FUELLED COMBINED HEAT AND POWER FOR DISTRICT HEATING

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SUMMARY

In this study, the integration of hydrogen-fuelled combined heat and power (CHP) plants is investigated. To this end, a rollout study based on expert knowledge and a literature review will be conducted, accompanied by a techno-economic assessment of a reference power plant operating with hydrogen-fuelled CHP generation. In this assessment, the influence of the hydrogen price on the operation is analysed, and its competitiveness with other heat power plants is evaluated. Preliminary results indicate that, for meeting district heating demand, competition is strong with heat pumps. However, CHPs begin to ramp up as hydrogen prices decrease to around 3 €/kg, even though only the day-ahead market is considered for purchasing and selling electricity.

Keywords: Hydrogen-fuelled combined heat and power, CHP, rollout study, techno-economic assessment

INTRODUCTION

In 2023, the EU-27 alone consumed 483 TWh of natural gas and work gas, 113 TWh of hard coal, and 48 TWh for powering CHPs (Eurostat 2022). Although these values are decreasing, a clear path must be established to reduce them to zero (IEA, International Energy Agency). There are several possible approaches to substituting CHPs fired by non-renewable energy sources, such as switching to alternative technologies for heat generation, like heat pumps and power-to-heat plants. Alternatively, fossil fuel-fired CHPs can be replaced with CHPs powered by fully renewable gases, such as green hydrogen.
This study will focus on substituting or retrofitting existing CHPs with fully hydrogen-ready CHPs, paving the path for fully dispatchable combined heat and power generation based on renewable hydrogen.
Therefore, a rollout study will be conducted to assess the potential of hydrogen-fuelled CHPs. This will be based on expert knowledge regarding market potential and technical feasibility, complemented by a review of relevant literature. The rollout study will be accompanied by a representative techno-economic assessment of a reference power plant, modelled with retrofitted CHPs.

TECHNO ECONOMIC ASSESSMENT OF A REFERENCE POWER PLANT

In this part of the study, a reference power plant featuring multiple technologies for generating heat and power in combination with hydrogen-fuelled CHPs is analysed. As shown in Figure 2, the plant is connected to both the electricity and hydrogen grids. In addition to drawing hydrogen from the hydrogen grid, a proton exchange membrane electrolyzer (PEMEL) with a capacity of 40 MWe can convert electrical energy into hydrogen, which can then be used in the CHPs. For energy buffering, an underground hydrogen storage with a capacity of approximately 400 000 m³ and a thermal storage with 3 GWh are modeled.

To meet the demand of the local district heating grid, a variety of technologies are considered. Alongside the hydrogen-fuelled CHP generator set with a capacity of approximately 200 MWth, a power-to-heat unit with a capacity of 30 MWe converts electrical energy into thermal energy with an efficiency close to 100%. Three different heat pumps upgrade anergy from various temperature levels to the desired temperature of the local heat grid. One heat pump, with a capacity of 60 MWe, utilizes external heat supplied from the neighboring sea.

Additionally, a cascade of two heat pumps upgrades the low-temperature output of the hydrogen-fuelled CHPs from 30°C to the electrolyzer's waste heat temperature of 60°C, and further to the desired temperature of the district heating grid.

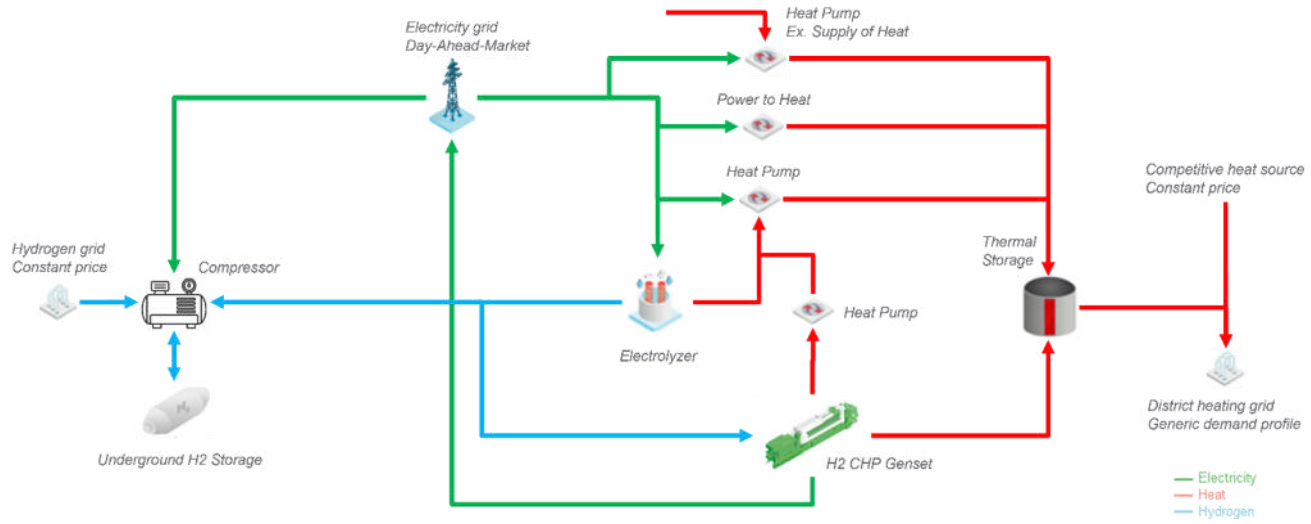


FIGURE 2: CONSTELLATION OF THE ANALYSED REFERENCE POWER PLANT

The techno-economic assessment is conducted with a deterministic time-series simulation approach accompanied by a operational optimization as depicted in the flowchart in **Fehler! Verweisquelle konnte nicht gefunden werden.**. To represent the power plant in the simulation, detailed models of the technologies were developed using AITs TESCA framework (Kapeller et al.). In addition to existing models of a heat pump and a PEMEL, the hydrogen-fuelled CHP and the thermal storage were newly set up with a high level of details. To ensure optimal plant operation, an optimization model was impemented using IESopt (Strömer et al. 2021-2024) to minimize the costs associated with meeting the heat demand. It is assumed that electricity is traded at volatile prices on the day-ahead market (2024) (ENTSO-E Transparency Platform) while hydrogen purchased from the hydrogen grid is assumed to have a time-invariant price. The heat demand for the district heating network was generated using the hotmaps dataset (Mostafa Fallahnejad 2019) scaled to an annual heat demand of approximately 1 TWh. To evaluate the economic dispatch of the overall power plant, it is considered that the plant must compete against a competitive heat source, which is modeled with a time-invariant heat price. Both the hydrogen price and competitive heat price were varied within a certain range to assess their influence on the operation of the power plant and its different technologies.

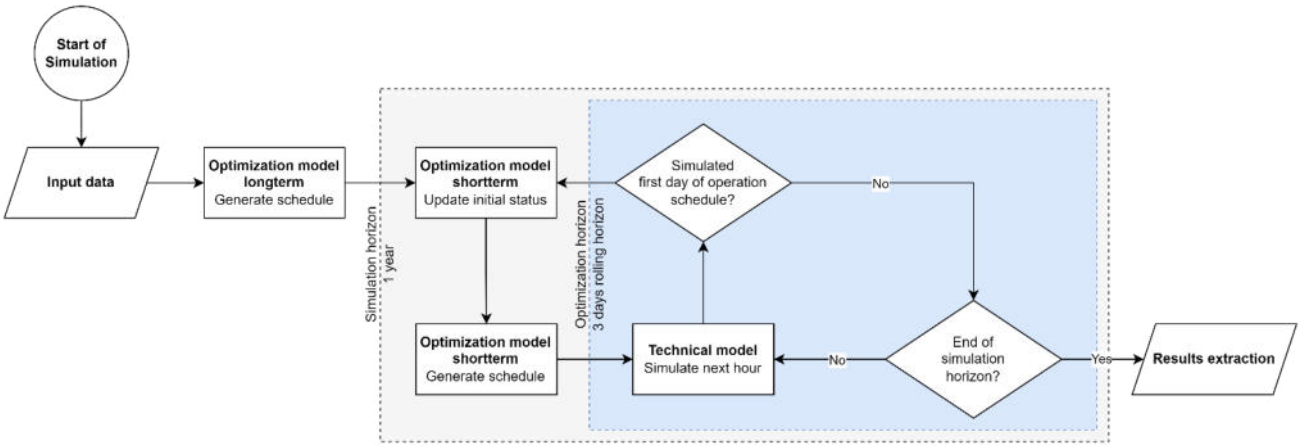


FIGURE 1: FLOWCHART OF THE DETERMINISTIC TIME-SERIES SIMULATION

The preliminary results depicted in Figure 3 show that the competition between the sea water heat pump and the hydrogen-ready CHPs is highly dependent on the hydrogen price. Since the hydrogen price essentially determines the marginal production costs of thermal energy output from the CHPs, the CHPs displace both the sea water

heat pump and the competitive heat source for low hydrogen prices. At higher hydrogen and competitive heat prices, the seawater heat pump displaces the CHPs. The contribution of the power-to-heat and the PEMEL waste heat to meeting the heat demand are negligeable, as they do not exceed 2.5 %. These results should be considered as a baseline, since only trading on the day-ahead market was considered for electricity. Therefore, CHP dispatch could increase through value stacking, such as providing grid services to the electric grid. This would enhance the profitability of CHPs, as they are the only technology in the system capable of producing both heat and power.

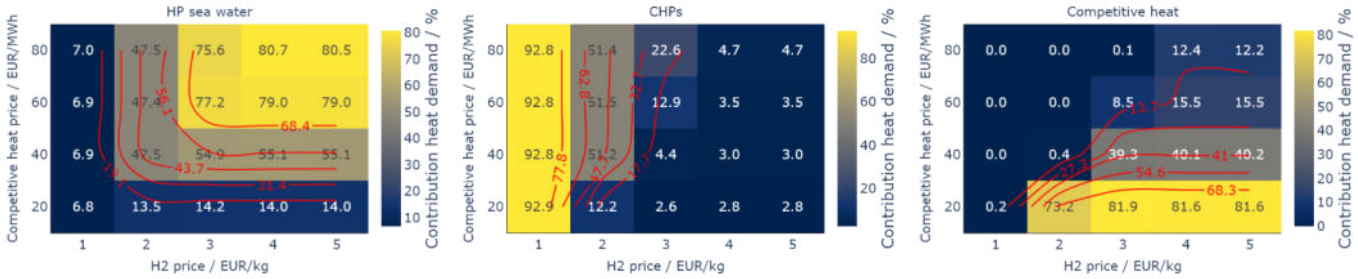


FIGURE 3: CONTRIBUTION TO THE ANNUAL HEAT DEMAND (2024) OF THE LOCAL DISTRICT HEATING NETWORK BY THE SEA WATER HEAT PUMP (LEFT), CHPS TOTAL HEAT OUTPUT (MIDDLE) AND COMPETITIVE HEAT SOURCE (RIGHT)

REFERENCES

ENTSO-E Transparency Platform. Available online at https://iop-transparency.entsoe.eu/, checked on 9/4/2025.

Eurostat (2022): Fuel used in combined heat and power.

IEA, International Energy Agency: Net Zero by 2050 - A Roadmap for the Global Energy Sector.

Kapeller, Judith; Maggauer, Klara; Patha, Andreas; Reisz, Petra; Wimmer, Yannick; Kathan, Johannes: Techno-Economic System and Component Analysis for Hybrid Power Plants. In.

Mostafa Fallahnejad (2019): Hotmaps-data-repository-structure. in Hotmaps-Wiki. Available online at https://www.hotmaps-project.eu/, checked on 9/4/2025.

Strömer, Stefan; Daniel, Schwabeneder; contributors (2021-2024): IESopt: Integrated Energy System Optimization: AIT Austrian Institute of Technology. Available online at https://github.com/ait-energy/iesopt.

CONFERENCE TOPIC

1.08. Future District Heating and Cooling Solutions

PILOT STUDY OF A WASTE-HEAT-DRIVEN SORPTION HEAT TRANSFORMER FOR LOW-CARBON COOLING AND HEATING IN A MUNICIPAL DISTRICT ENERGY SYSTEM

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SUMMARY

The City of Burnaby is advancing a large-scale district energy (DE) system that utilizes waste heat from Metro Vancouver's Waste-to-Energy facility to provide low-carbon heating for urban buildings. In partnership with Simon Fraser University, a novel waste-heat driven sorption heat transformer (TRL6) has been developed and piloted to enable delivering both heating and cooling efficiently. The system uses water as a natural refrigerant, eliminating the need for electricity and avoiding harmful synthetic refrigerants. A proof-of-concept prototype was installed and tested at Burnaby City Hall. The unit demonstrated an average cooling power of approximately 0.5 kW and a coefficient of performance (COP) of 0.64 for cooling and COP of heating of 1.47. These results were achieved using a waste heat source at around 80 °C and a condenser temperature of approximately 32 °C, validating the technical feasibility of the system under real-world operating conditions.

INTRODUCTION

The City of Burnaby is developing a major district energy (DE) system to harness waste heat from Metro Vancouver's Waste-to-Energy facility, which processes more 260,000 tonnes of garbage annually and currently generates electricity for nearly 16,000 homes. At present, only a portion of the facility's heat is captured and converted into electrical power. By implementing a DE system, this underutilized thermal energy can instead be distributed to heat critical infrastructure, including approximately 25,000 residential units, Burnaby Hospital, and the British Columbia Institute of Technology (BCIT). Once completed, this initiative will be among the largest DE projects in Canada, with the potential to reduce carbon emissions by more than 22,000 tonnes per year.

Simon Fraser University, in collaboration with the City of Burnaby, is leading a multi-year R&D initiative to develop and pilot a patented waste-heat driven sorption heat transformer technology [1] integrated within the city's DE network. This pioneering system utilizes waste heat from the Waste-to-Energy facility to enable delivering scalable, cost-effective, and sustainable heating and cooling solutions.

The sorption heat transformer, currently at Technology Readiness Level 6 (TRL6), is designed to operate with DE-supplied heat at 80–90 °C and can deliver both cooling and heating with negligible electricity input. The system contains no moving parts and uses environmentally friendly materials, including water as a natural refrigerant, thus avoiding synthetic refrigerants and rare-earth elements. This innovation aligns with broader climate action goals aimed at reducing urban carbon emissions and supporting net-zero transitions.

PILOT STUDY RESULTS

The first proof-of-concept prototype was built and operated at Burnaby City Hall for one month (August–September 2025). The system included a capillary-assisted low-pressure evaporator (CALPE), a dropwise condenser, and two identical sorber beds equipped with compact heat exchangers to minimize thermal inertia.

Figure 1 shows the installed prototype, which was designed to deliver approximately 500 W of cooling as a proof-of-concept, along with the user interface and controller used to monitor system parameters and operating conditions. To simulate a waste heat source, a boiler supplied hot water at approximately 80 °C. An air-cooled condenser provided a cooling sink at approximately 32 °C; the condenser outlet was subsequently used as the cooling inlet for the sorber beds during the adsorption cycle.

(a) (b)

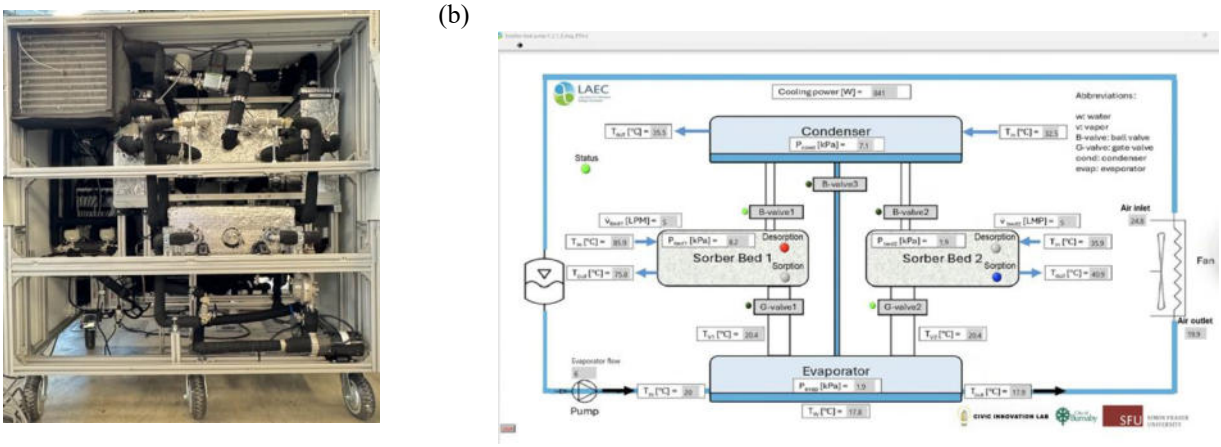


Figure 1. An image of (a) the prototype and (b) user interface and controller.

The system operated reliably for one month, withstanding fluctuations in both the waste heat source (72–87 °C) and the cooling sink (30–47 °C). It consistently produced chilled water at ~19 °C and hot water at ~39 °C. A small air handling unit was also integrated into the prototype and delivered cooled air (~19 °C) to the mezzanine level of City Hall, demonstrating its applicability for space cooling.

Figure 2 presents a representative snapshot of the instantaneous cooling power over a 12-hour test period. The prototype delivered approximately 500 W of cooling with a cycle time of 12 minutes. The measured coefficient of performance (COP) was ~0.64 for cooling and ~1.47 for heating. These results demonstrate the system's efficiency, resilience and reliability under real-world conditions.

There remains considerable potential for further optimization and performance enhancement, which will be addressed in our scaled-up prototype scheduled for deployment at a new site in summer 2026.

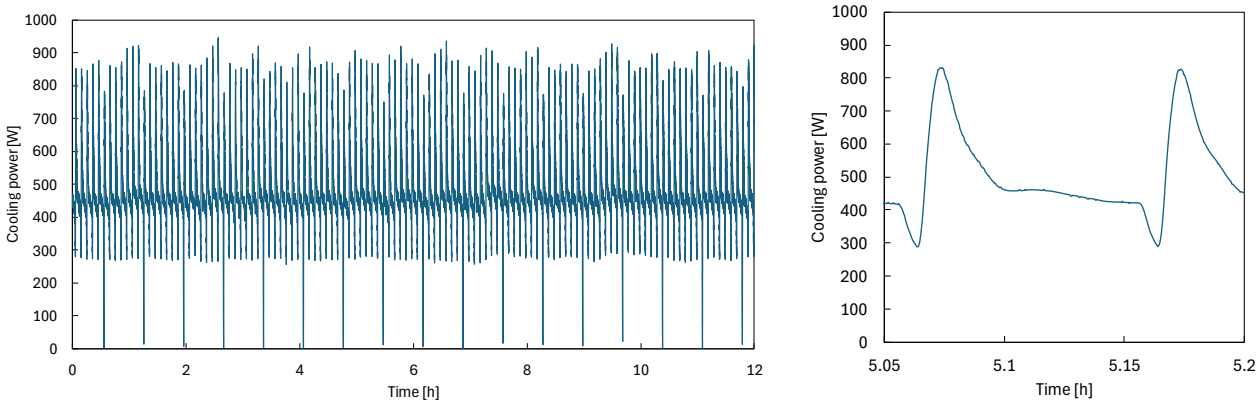


Figure 2. Cooling power measurement of the prototype

REFERENCES

[1] Bahrami, Majid, “Sorption Heat Transformer and Thermal Storage,” Canadian Patent 3177348

CONFERENCE TOPIC

1.08. Future District Heating and Cooling Solutions

INTRODUCTION TO THE PROJECT INNOBELS - DEVELOPMENT AND ASSESSMENT OF INNOVATIVE CONTAINER CONCEPTS FOR LATENT HEAT STORES IN COLD SOLAR HEATING NETWORKS

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SUMMARY

This paper outlines the collaborative research project, entitled innoBeLs, the aim of which is to develop and evaluate innovative container concepts for latent stores in solar cold district heating networks. The project has started in the beginning of 2025 and will end by the end of 2028. The primary focus is on the development and implementation of innovative economic and ecological container concepts for latent storage tanks. These tanks are intended for commercial use in solar cold heating networks. Concrete tanks, which are characterised by their high cost, emission and energy intensity, have been utilised as latent or ice storage tanks. These tanks feature two heat exchanger coils, which are composed of PE-X (cross-linked polyethylene) pipes attached to aluminium profiles. In comparison, the new innovative container concepts to be developed should reduce the negative environmental impact and the use of resources by at least 50 per cent and cut costs by at least 20 per cent.

INTRODUCTION

In solar-powered cold district heating networks, ice storage systems are a key technology for seasonal energy storage. However, the concrete stores currently in use, which feature two heat exchanger coil loops made of PE-X and a mounting structure made of aluminium profiles, have significant environmental impacts due to material usage and the primary energy required for manufacturing and disposal.



Fig. 1: Photo shows a state-of-the-art ice storage, sizes ranging from 45 m³ to 1500 m³ available on the market.

The innoBeLs research project is developing an innovative and resource-efficient container concept that will address this issue. Following the findings of previous research projects such as Sol4City (Development of integrated solar energy supply concepts for climate-neutral buildings of the city of the future) and SolKaN2.0

(second generation cold solar district heating), alternative construction methods such as pit thermal energy stores or gravel-water thermal energy stores are currently under investigation. Initial analyses indicate that such concepts have the potential to reduce environmental impacts and greenhouse gas emissions by up to 50% and lifecycle costs by approximately one-third. Increased ice storage capacity leads to greater potential savings.

A key research aspect of innoBeLs is the optimisation of the heat exchangers, given that their length already reaches several kilometres for a store volume of 100 m³. Innovative design approaches are being developed to minimise material consumption, costs, and ecological impact. Additionally, the project focuses on the scalability and standardisation of the newly developed container solutions to drive cost reductions and promote wider market penetration of this technology.

Another challenge related to latent heat stores, such as ice stores, is the detection of the state of charge, as the charge level can change even at a constant temperature. In order to address this challenge, reliable and cost-effective solutions are currently being developed.

In order to achieve the objectives of the project, a programme of experimental work and simulations is to be conducted. These simulations will include thermal, structural, fluid dynamic, and system simulations. The present programme of studies and simulations will investigate aspects such as the formation of ice on new container components, the structural stability of the new container concept, the functionality of new state of charge sensors and the system integration of the new container design.

The results of analysing several newly developed container concepts will inform the implementation of an innovative ice store in a pilot plant. This will be achieved by subjecting the concept to real operating conditions, measurement, and comprehensive evaluation. The evaluation will consider the economic and ecological impact of the concept across its entire lifecycle.

The utilisation of efficient ice stores has become increasingly pertinent in the context of the growing demand for district heating networks in Germany, particularly in new residential areas. This is in conjunction with cold heating networks and decentralised heat pumps in individual buildings. Consequently, the innoBeLs project makes a significant contribution to the sustainable heat supply of the future.

METHODOLOGY

The starting point for the development work is already known container concepts, such as Pit thermal energy store (PTES) and Gravel-water pit thermal energy store (GW-PTES). In addition, further promising container technologies are to be researched and tested in a technology screening process. Based on this, several innovative container concepts for latent storage will be developed and evaluated. Evaluation criteria include the results of life cycle assessment (LCA) and life cycle costing (LCC) analysis for both existing and new container concepts as well as technical aspects. The resulting favoured container concept will be implemented in a test facility and tested over a period of at least one year. At the end of the project, innovative container concepts will be available, one of which will be implemented in the test plant in real use, analysed in terms of measurement technology and examined in detail from an economic and ecological point of view along the entire life cycle.

Moreover, the standardisation of the concept, the preliminary design, the documentation and the handover will be constituent elements of the project.

As shown in Fig. 2, the project is divided into six work packages, which address the following topics: In the initial work package, the requirements for container concepts are developed and elaborated with preliminary experimental and simulation studies.

Subsequent to this, the implementation of the project (WP3) is to be followed by the testing phase (WP5), which is to be conducted through monitoring. Concurrently, the WP4 team will address life cycle assessment and life cycle costing issues. The fifth work package deals with the standardisation of the preferred container concept. The project management and public relations activities that accompany the project serve to complement the work packages.

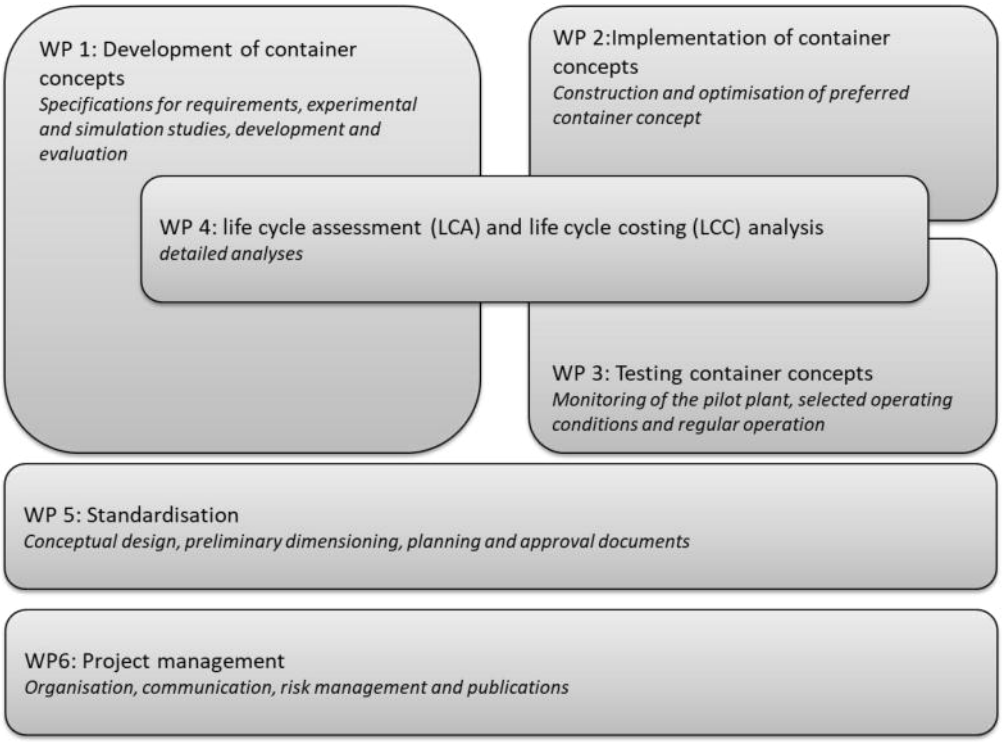


Fig. 2 The figure shows the six work packages into which the innoBeLs project is divided.

The preliminary findings and first comprehensive analyses of preferred container solutions will be outlined in the full paper.

REFERENCES

Sol4City, Drück, H., Lott, S., Juschka, W., Ullmann, J., Lang, S., Huber, P., Bonk, N., & Bestenlehner, D. (2024). Abschlussbericht: Entwicklung integrierter solarer Versorgungskonzepte für klimaneutrale Gebäude der „Stadt der Zukunft“ (Sol4City) (Version 06.11.2024). Institut für Gebäudeenergetik, Thermotechnik und Energiespeicherung (IGTE); Viessmann Climate Solutions SE (VCS)

SolKaN2.0,enargus, https://www.enargus.de/detail/?id=32172273, [29.07.2025]

ACKNOWLEDGEMENT

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CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: Future District Heating and Cooling Solutions

DEMONSTRATION OF SUCCESSFUL MODERNISATION AND RETROFITTING IN AUSTRIAN BIOMASS-BASED DISTRICT HEATING NETWORKS

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SUMMARY

The work is dedicated to the development and demonstration of holistic modernisation and retrofitting concepts of biomass-based district heating networks. Through the concept development, the corresponding technological and non-technical measures, as well as the necessary (holistic) system-wide steps, were tested, highlighted, and their combined potential was shown. The developed solutions were subsequently implemented and realised in three different biomass-based district heating networks in Austria, accompanied by data evaluation and system validation, including life cycle and value chain analysis. Identified optimisation potentials and experiences from the entire innovation process demonstrate quantitatively the technical, economic, and ecological benefits and impacts. Moreover, scaling scenarios were developed to generate and assess market potential, as well as to determine the benefits and effects on the overall energy system.

DISTRICT HEATING AND THE ROLE OF BIOMASS-BASED HEATING PLANTS IN AUSTRIA

District heating has been a crucial component of Austria's energy infrastructure for several decades. Initially dominated by fossil-fuel-based systems in large cities, the last three decades have seen a significant shift towards biomass-based networks in smaller towns and rural areas. Today, Austria's DH systems produce approximately 85 PJ of energy annually, with nearly half derived from biomass. These networks meet about 25% of the national demand for heating and warm water [1]. The proliferation of biomass heating plants – approximately 2,400 in number, supplemented by 150 biomass-based combined heat and power (CHP) plants [2] – has been driven by the technology's efficiency, regional availability, and renewable nature. However, many of these systems are now 20–30 years old and face new challenges. These include seasonal inefficiencies, particularly during low summer loads, high distribution losses, and the need to integrate local renewable sources to meet future climate and energy policy goals.

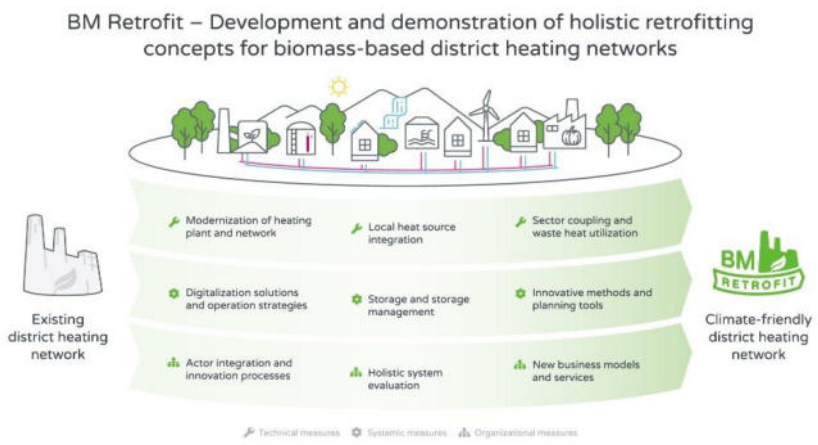


Figure 4: Methodological framework within BM Retrofit, Source: Green Energy Lab

INNOVATION AND RELEVANCE

To address the needs, within the BM Retrofit [3] project, a methodology based on three different pillars (see Figure 1) was developed. This concerns technical measures, systemic measures, as well as organisational measures and subsequently economic aspects. The holistic systemic approach results in high synergy potentials

to a) adapt and further develop existing district heating networks to meet future requirements, b) achieve corresponding climate goals, and c) strengthen economic benefits, including local value chain creation. However, this systemic and holistic approach to developing retrofitting concepts, which extends beyond individual technological solutions and involves the accurate integration of systems, combined with the comprehensive involvement of relevant stakeholders, including the expansion of services and business models, is currently not being applied on the market, and the available potential is not being fully utilised.

DEMONSTRATION IN REAL-LIFE DH NETWORKS

BM Retrofit utilised demonstrator sites (Wald im Pinzgau, Saalfelden, Kreuzstetten) to showcase, validate, and optimise the developed retrofitting concepts, and drew on these experiences to derive best practices. Within detailed data and system evaluation and validation, the technical, economic and ecological benefits and impacts of the realised retrofitting and modernisation measures within the demonstrators were investigated. In the following, the main realised measures at the demonstration sites are described briefly:

- Wald im Pinzgau: integration of a 250 kW heat pump to utilise low-temperature waste heat from a nearby hydropower plant (cooling cycle); power-to-heat unit to ensure operational redundancy and support feed temperature adjustments; 30,000-litre thermal storage tank to increase flexibility and cover load fluctuations.
- Saalfelden: technical modernisation of the biomass boiler system, including a flue gas condensation system; integration of a cascading heat pump concept (3x250 kW) into the flue gas condensation to further increase the efficiency; innovative control strategy using CO lambda sensors to optimise biomass boiler operation; buffer storage tank with a volume of 150,000 litres.
- Kreuzstetten: technical optimisation of the biomass heating plant to overcome current challenges (e.g. insufficient summer operation, elevated system temperatures); targeted network densification based on simulation and spatial energy planning; improvement of boiler control and buffer storage management to reduce unnecessary load fluctuations; new business model.

CONCLUSIONS

Within BM Retrofit, innovative technical concepts (e.g. flue gas condensation systems, heat pump systems, storage technologies, sector coupling, waste heat utilisation, etc.) were developed and optimised for efficient system integration. This will ensure that innovative measures can be further improved and integrated, resulting in more sustainable and economical operations that utilise reduced resources and achieve environmental savings. BM Retrofit enables, for the first time, the realisation of a sustainable energy system, a) with increased overall efficiency and flexibility, b) with the best possible use of renewable and local energy sources, c) with full exploitation of synergies of existing infrastructures, and d) with the creation of a future-proof and resilient system. Through this intelligent combination and holistic approach, it was possible to a) adapt and further develop existing biomass-based district heating networks to meet future requirements (e.g. decentralized generation and storage, load changes, different temperature levels, low summer load with increased heat losses, necessary enlargement, etc.), b) achieve corresponding climate goals and c) strengthen economic benefits including local value chain creation.

REFERENCES

[1] FGW – Fachverband der Gas- und Wärmeversorgungsunternehmungen: GAS UND FERNWÄRME IN ÖSTERREICH, ZAHLENSPIEGEL, 2024

[2] Österreichischer Biomasseverband: Bioenergie Atlas Österreich, 2023

[3] BM Retrofit project website

CONFERENCE TOPIC

Abstract refers to Technologies and Systems for Buildings, Industry, Districts, Cities and Regions - Future District Heating and Cooling Solutions.

ASSESSING THE ECONOMIC POTENTIAL OF GERMAN LAKES AS HEAT SOURCES FOR LARGE-SCALE HEAT PUMPS

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SUMMARY

This study presents the first comprehensive and national assessment of the economic potential of German lakes and reservoirs as heat sources for large-scale heat pumps. Using a hierarchical framework, the research evaluates the theoretical, technological, extractable, economic, and utilization potential of all German standing water bodies with a surface area larger than 10 hectares. The theoretical potential is 76.84 TWh per year, equivalent to 25% of the total annual heat demand within a 5 km radius of all such lakes (301.39 TWh). The cost-effectiveness of lake-based district heating systems is compared with that of individual air-source heat pumps using an Economic Index, incorporating spatially resolved heat demand data. The methodology for modelling district heating networks in economically promising areas progresses from the theoretical maximum to the most restrictive utilization potential. The analysis examines how factors such as the distance of heat demand to lakes and heat demand density influence the economic viability of lake-source heating systems.

Keywords: Large-scale water-source heat pumps, district heating, heat extraction potential, economic analysis

INTRODUCTION

Utilizing lakes as renewable heat sources for large-scale heat pumps represents a promising pathway to decarbonizing heating systems in Germany. Despite growing interest in aqua thermal energy, no comprehensive national analysis has yet been conducted to determine the economic potential of German lakes as heat sources. Besides that, German regulations are heterogeneous and provide no clear guidelines on the topic. Previous research has been fragmented across spatial scales and methodological approaches. National studies by Kammer (2018) and Salaymeh et al. (2025) focused on different lake size thresholds and assessment criteria. Regional studies provided valuable but geographically limited insights (Singer et al. (2022), Lang et al. (2024)). International studies demonstrated varying approaches, from hydrodynamic modelling in Switzerland (Gaudard et al. 2019) to European-scale GIS mapping by Manz et al. (2024) and large lake analysis by Eggimann et al. (2023). This study addresses this gap by providing the first systematic evaluation of the economic potential of German lakes as heat sources for large-scale heat pumps through a hierarchical framework analysis.

METHODOLOGY

This study establishes a hierarchical framework for analysing lake-based heat extraction potential, progressing from theoretical maximum to economically usable potential. The methodology encompasses five distinct potential categories: theoretical, technological, extractable, economic, and utilization potential.

Theoretical Potential: The theoretical heat extraction potential considers all German lakes with surface areas exceeding 10 hectares, utilizing volume data from the HydroLAKES (Messager et al. (2016)) global database. The maximum extractable heat was calculated using the following formula:

$$Q_{theoretical} = V \times \rho \times c_p \times \Delta T \quad \text{(eq. 1)}$$

where V represents total lake volume (66.18 bcm), ρ is water density, c_p is specific heat capacity, and ΔT assumes a 1K temperature difference available for extraction.

Technological Potential: A comprehensive literature review of existing installations was conducted and supplemented with industry reports. The analysis evaluated scalable heat pump systems adaptable to various lake conditions.

Extractable Potential: Following Salaymeh et al.´s (2025) framework, sustainable heat extraction rates were calculated using:

$$Q_{extractable} = \dot{V}_{sus} \times \rho \times c_p \times \Delta T_{hex} \times h \quad \text{(eq. 2)}$$

where $\dot{V}_{sus}$ (based on the ecologically acceptable temperature limit within the heterogeneous German regulations) represents sustainable volumetric flow rate, ΔT_{hex} is the temperature difference across heat exchangers, and h represents annual full load hours.

Economic Potential Evaluation: An Economic Index (EI) was developed based on Eggimann et al. (2023), comparing lake-based district heating systems with individual air-source heat pumps. The index evaluates net present value differences in electricity costs over lifetime, normalized by network construction costs and distance:

$$EI = [C_{el,air} \times \left(\frac{E_h}{COP_{air}}\right) - C_{el,water} \times \left(\frac{E_h + E_{loss}}{COP_{water}}\right)] \times f_{inflation} \times T]/[C_{pipe} \times d] \quad \text{(eq. 3)}$$

Where $C_{el,air}$ and $C_{el,water}$ are electricity costs, COP_{air} and COP_{water} the respective coefficients of performance, E_h annual heating demand, E_{loss} distribution losses, $f_{inflation}$ the electricity price inflation factor, T system lifetime, C_{pipe} pipe construction cost per meter, and d network distance. The EI was calculated for one-hectare raster cells using spatially resolved heat demand data from Hotmaps.eu. Future refinement of both economic and extractable potentials will incorporate seasonal water temperature variations through the General Lake Model (Hipsey et al. 2019) to capture the temporal resolution of thermal potential estimates.

RESULTS

The analysis reveals that German lakes larger than 10 hectares possess a theoretical thermal potential of 76.84 TWh annually, equivalent to 25% of the total heat demand (301.39 TWh) within a 5 km radius of all lakes. The overlay of thermal potential with regional heat demand demonstrates a promising alignment, indicating favourable conditions for economically viable lake-source heating systems. One-hectare locations with an EI ≥ 1 have a total heat demand of 14.26 TWh per year and provide an initial indication of where lake-based heat pump installations may be more economically attractive than individual air-source systems. However, this indicator changes if neighbouring cells already have economically viable networks.

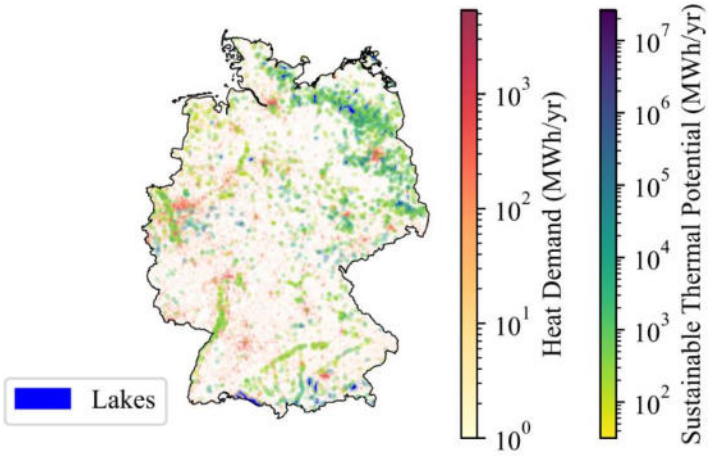


FIGURE 5: EXTRACTABLE THERMAL POTENTIAL OF GERMAN LAKES AND HEAT DEMAND

REFERENCES

Eggimann, Sven; Vivian, Jacopo; Chen, Ruihong; Orehounig, Kristina; Patt, Anthony; Fiorentini, Massimo (2023): The potential of lake-source district heating and cooling for European buildings. In: Energy Conversion and Management 283, S. 116914. DOI: 10.1016/j.enconman.2023.116914.

Gaudard, Adrien; Wüest, Alfred; Schmid, Martin (2019): Using lakes and rivers for extraction and disposal of heat: Estimate of regional potentials. In: Renewable Energy 134, S. 330–342. DOI: 10.1016/j.renene.2018.10.095.

Hipsey, M. R., Bruce, L. C., Boon, C., Busch, B., Carey, C. C., Hamilton, D. P., Hanson, P. C., Read, J. S., de Sousa, E., Weber, M., and Winslow, L. A.: A General Lake Model (GLM 3.0) for linking with high-frequency sensor data from the Global Lake Ecological Observatory Network (GLEON), Geosci. Model Dev., 12, 473–523, https://doi.org/10.5194/gmd-12-473-2019, 2019.

Kammer, Henriette (2018): Thermische Seewassernutzung in Deutschland. Bestandsanalyse, Potential und Hemmnisse seewasserbetriebener Wärmepumpen. DOI: 10.1007/978-3-658-20901-8_6.

Lang, Susanne; Panitz, Felix; Nikolov, Alexander; Drechsler, Björn; Ahrendts, Fabian; Meier, Nadezda (2024): Erneuerbar, Effizient, Regional - Potenziale von Großwärmepumpen in Brandenburg und Sachsen.

Messager, M.L., Lehner, B., Grill, G., Nedeva, I., Schmitt, O. (2016). Estimating the volume and age of water stored in global lakes using a geo-statistical approach. Nature Communications, 7: 13603. https://doi.org/10.1038/ncomms13603

Manz, Pia; Billerbeck, Anna; Kök, Ali; Fallahnejad, Mostafa; Fleiter, Tobias; Kranzl, Lukas et al. (2024): Spatial analysis of renewable and excess heat potentials for climate-neutral district heating in Europe. In: Renewable Energy 224, S. 120111. DOI: 10.1016/j.renene.2024.120111.

Salaymeh, Abdulraheem; Eck, Johannes; Holler, Stefan; Peters, Irene (2025): Techno-spatial evaluation of the sustainable thermal potential and water withdrawal rates of waterbodies. In: Energy 332, S. 137093. DOI: 10.1016/j.energy.2025.137093.

Singer, Kathrin; Voßhenrich, Vincent; Walker-Hertkorn, Simone (2022): Potentialanalyse der thermischen Nutzung von Seen im Landkreis Karlsruhe.

THE FIVE-STAGE TRANSFORMATION OF THE AUSTRIAN HOUSING STOCK TOWARDS NET ZERO AND BEYOND

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SUMMARY

The Austrian building sector accounts for approx. 9% of the national GHG emissions according to the national greenhouse gas inventory, where only operational carbon emissions are attributable to the sector. However, the share rises to 33%-40% if whole lifecycle carbon emissions are considered. Therefore, the transformation of the building stock is crucial for reaching net zero carbon emissions. Using the example of the Austrian housing stock with a focus on the limited-profit housing stock, five stages of this transformation are distinguished: (1) Improving energy efficiency by thermal refurbishment (2) Decarbonisation of heating systems, (3) Expansion from the property to the neighbourhood level (4) Decarbonisation in the whole life cycle (5) Moving beyond net zero through nature-based solutions and carbon storage.
While stage (1) has passed its peak, stages (2) and possibly (3) are the ones with the highest carbon-saving effects today. However, stages (4) and (5) will require further attention if international climate goals are to be met.
Keywords: building sector; net zero; energy efficiency; decarbonisation; embodied carbon, transformation

RESEARCH CONTEXT AND METHODS

Following political targets on European ('European Green Deal' and its associated legislation) as well as on national level (climate-neutrality until 2040), the Austrian building sector is in the process of a major transformation.
According to the Austrian inventory (Umweltbundesamt 2025), the building sector accounts for 9.2% of the national GHG emissions and has reduced its emissions by 51% since 1990. However, this definition only considers the operational phase of buildings, mainly the energy consumed for heating, cooling and cooking, and even then not to its full extent. The energy supplied by district heating is attributed to the energy sector, while the energy associated with the construction itself and the manufacture of building materials is attributed to the industrial sector.
In a more comprehensive view considering the whole lifecycle of a building (including embodied carbon), the built environment accounts for approx. 33-40% of the total carbon emissions, depending on the scope and the region (UNEP 2021, Truger et al. 2022). Following this approach, decarbonisation efforts in the building sector need to go beyond the operational phase. The author takes up this holistic understanding of decarbonisation and analyses the progress in the transformation of the Austrian housing sector, with a focus on the limited-profit housing stock.
The paper shows

- A new conceptual approach to analysing the transformation of the Austrian housing stock in five stages, each marking both a temporal phase and a change in perspective
- A synthesis of relevant literature, energy- and building-related statistical data with data from surveys conducted by the Austrian Federation of Limited-Profit housing associations

- A model calculation of the progress and the remaining path to climate neutrality in the housing sector in terms of CO_2-reduction requirements and a rough estimate of investment costs (where possible)

MAIN PART – THE FIVE STAGES OF THE TRANSFORMATION OF THE BUILDING SECTOR

The following five stages of the transformation of the building sector are identified:
1. Improving energy efficiency by thermal refurbishment of buildings: Starting in the late 1980s, this phase peaked around 2010. Having had strong impacts on the reduction of GHG emissions until the first decade of the 21st century, these are comparatively low today due to various reasons (Hüttler et al 2023, Amann et al 2022).
2. Decarbonisation of heating systems: Replacing heating systems based on fossil sources (coal, oil, gas) by district heating or renewable energy systems (mainly heat pumps pellets, biomass). Starting around 2000, this stage also had a first peak around 2010 and second around 2022, with strong CO_2 reduction effects in these years (Amann et al 2022, Gutheil-Knopp-Kirchwald 2020).
3. Expansion of decarbonisation efforts from the property level to the neighbourhood level: renewable energy communities and more comprehensive concepts such as plus energy districts began to spread in the 2020s
4. Decarbonisation in the whole life cycle with a focus on embodied emissions and circularity: Despite intense research (e.g. Röck et al 2020, Truger et al 2022) and legislation pointing in this direction (e.g. EPPD recast 2024), the consideration of whole life cycle (WLC) carbon emissions and circularity in the construction sector stands at an early stage of its implementation in Austria.
5. Beyond climate neutrality to climate positive effects through nature-based construction: In this stage, the target is no longer to reduce carbon emissions from buildings to (almost) zero and to minimise climate harm, but to achieve net negative emissions through natural carbon storage and the (partial) replacement of carbon-intense building materials such as concrete or steel. Through the extensive use of bio-based materials (timber, biobased insulation material,..) in new buildings and renovations, the built environment could eventually transform from a carbon emitter to a carbon sink (Churkina et al., 2020, Schellnhuber 2022).

The article analyses the progress and the challenges in each of these five stages for the Austrian housing sector, with a focus on the limited-profit housing sector. Using national data (energy statistics, census and microcensus data, greenhouse gas inventory), surveys by the Austrian Federation of Limited-profit Housing associations and relevant studies, it is shown that the carbon saving effects of stage one (thermal insulation) has passed its peak whereas stage two (decarbonisation of the heating systems) and possibly also stage three (neighbourhood approach) today are the ones with the highest impact for CO_2-reduction in the existing stock. However, for new developments, the reduction of whole life carbon emissions (stage 4) and the approaches to „repair“ the climate by nature-based construction (stage 5) will require further attention if international climate goals are to be met.
In the methodological part of the study, the availability and reliability of building and energy related data sources in Austria is critically assessed.
As far as data and literature allows it, also a rough estimate on the (remaining) investment costs and the carbon saving potential for each transformation stage until 2040 is given.
The paper finishes with conclusions and some ideas on how to facilitate and accelerate the transformation of the Austrian housing sector towards climate neutrality and beyond.

SELECTED REFERENCES

Amann, W., et al. (2022), Studie zur langfristigen Finanzierung der Wärmewende. Im Auftrag des Bundesministeriums für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie.

Churkina G, Organschi A, Reyer C P O, Ruff A, Vinke K, Liu Z, Reck B K, Graedel T E and Schellnhuber H J. (2020), Buildings as a global carbon sink *Nat. Sustain.*3 269–76

GBV (2024), Österreichischer Verband gemeinnütziger Bauvereinigungen – Revisionsverband: Verbandsstatistik 2024. Die gemeinnützige Wohnungswirtschaft in Zahlen. Online: www.gbv.at

Gutheil-Knopp-Kirchwald, G. (2020): Dekarbonisierung des Gebäudesektors im gemeinnützigen Wohnungsbestand. In: OIB aktuell 2.2020.

Hüttler, W., Gutheil-Knopp-Kirchwald, G., Kössl, G. (2023), Dekarbonisierung im gemeinnützigen Wohnungsbestand. In: Amann, W./Struber, Ch. (Hrsg,2023): Österreichisches Wohnhandbuch 2023. 11. Auflage. Linde Verlag, pp 50-64.

Röck, M. et al (2020), Embodied GHG emissions of buildings – The hidden challenge for effective climate change mitigation, Applied Energy, Volume 258, 2020, 114107, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2019.114107 .

Schellnhuber, H.-J. (2023), Saving the world by construction. In: Bauhaus Earth, Hans Joachim Schellnhuber, Rocio Armillas Tiseyra (Eds., 2023). Reconstructing the Future. Cities as Carbon Sinks. Birkhäuser Basel

Truger, B. et al (2022). Life cycle GHG emissions of the Austrian building stock: A combined bottom-up and top-down approach. IOP Conference Series: Earth and Environmental Science, 1078(1), Article 012024. https://doi.org/10.1088/17551315/1078/1/012024

UNEP (2021), Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector. Nairobi, Kenia.

Umweltbundesamt (2025), Klimaschutzbericht 2025.
https://www.umweltbundesamt.at/fileadmin/site/publikationen/rep0990.pdf

Weber, B., Berger, L. (2024), Zukunft Bestand. Ökosoziale Transformation von Wohnhausanlagen. Ruby Press

Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast) (EPBD). http://data.europa.eu/eli/dir/2024/1275/oj

CONFERENCE TOPIC

1.16. Transform Cities: Holistic Approaches to Sustainable Urban Energy
or
2.05. Marketing, dissemination and implementation strategies

COOLING DEMAND PATHWAYS UNDER CLIMATE AND SOCIO-ECONOMIC CHANGE

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SUMMARY

The rapid increase in space cooling demand across Europe is expected to drive a growth in the uptake of active cooling measures, such as air conditioners and other electricity-intensive devices. However, substantial uncertainty remains regarding the pace and distribution of this uptake, as well as its implications for electricity systems. This study investigates the future development of active cooling measures using high-resolution spatial socio-economic and climate data to develop a concrete technology stock model. The analysis aims to identify cost-efficient pathways, evaluate how well these approaches represent user behaviour, and assess the resulting system-level impacts. The findings will provide insights for planning energy systems resilient to rising cooling needs.

INTRODUCTION

Space cooling demand is increasing significantly in Europe due to rising temperatures, changing comfort expectations, and higher living standards. This growth translates into a proportional, yet often non-linear increase in the use of active cooling devices such as air conditioners. The diffusion of such technologies poses challenges for electricity systems, potentially leading to capacity constraints, peak load issues, and increased emissions if supplied with fossil-based power.

Despite its importance, the future uptake of active cooling remains highly uncertain. Preliminary Eurostat data already shows strong variation in historical adoption, ranging from less than 1% in Northern countries to more than 70% in Malta and Cyprus. Looking ahead, trajectories will depend not only on climatic changes but also on socio-economic drivers such as income growth, urbanization, and demographic change. Furthermore, the extent to which passive cooling measures such as shading, improved glazing, or thermal mass utilization are adopted will strongly influence both the demand for active cooling and the resulting load on the electricity grid.

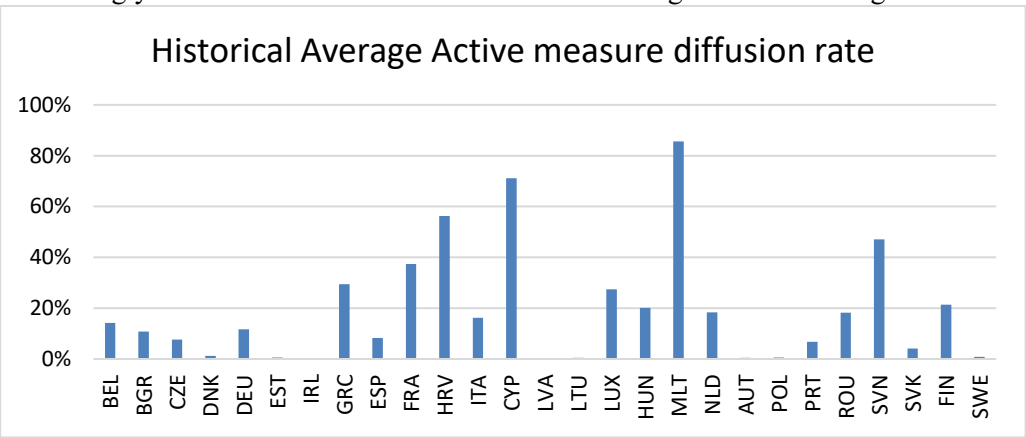


Fig. 1: Average annual diffusion rate of active cooling technologies in residential buildings [3]

To inform energy system planning, it is therefore crucial to understand how active and passive cooling uptake may evolve across Europe. This requires robust modelling approaches capable of capturing heterogeneity in building stocks and decision-making behaviour of building owners.

METHODOLOGICAL APPROACH

This study explores different approaches for projecting the uptake of cooling measures at building-stock level. Two complementary strategies are proposed:

- **Simulation-based modeling:** capturing the development of the building stock and cooling technology diffusion under scenario assumptions (e.g., socio-economic pathways, climate projections).
- **Optimization-based modeling:** using cost-minimization at the building level to represent investment decisions, thereby identifying minimum-cost pathways of active measure adoption.

High-resolution socio-economic data will be combined with climate projections to estimate spatially explicit cooling demand.

To demonstrate the implementation, the methodology will first be applied to a case study for Vienna, utilizing available local building and socio-economic data. This case study will serve both to validate the modeling framework and to highlight challenges and uncertainties before extending the analysis to the European scale.

EXPECTED OUTCOMES AND DISCUSSIONS

By comparing simulation and optimization approaches, the study seeks to identify how different modelling approaches represent the dynamics of cooling measure uptake. Particular attention will be given to whether optimization-based pathways underestimate behavioural, financial, or market frictions compared to simulation-based trajectories.

The expected contributions are:

- Projections of active cooling uptake across Europe under varying socio-economic and climatic conditions.
- Assessment of the role and diffusion of passive measures in reducing cooling demand.
- Insights into how methodological choices (simulation vs optimization) shape results and policy relevance.
- Discussion of implications for electricity grid planning and system integration.

Ultimately, this research aims to support the development of more resilient and cost-effective strategies for managing the growing challenge of cooling demand in Europe.

REFERENCES

[1] Isaac, M., and van Vuuren, D.P. (2009). Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. *Energy Policy, 37*(2), 507–521.

[2] Santamouris, M. (2016). Cooling the buildings – past, present and future. *Energy and Buildings, 128*, 617–638.

[3] Eurostat, 'Energy Consumption in Households'. [Online]

[4] Xiang, L., Chambers, J., Yilmaz, S., and Patel, M. (2021). A Monte Carlo building stock model if spoace cooling demand in Swiss service sector under climate change. *Energy and Buildings*, Volume 233, on 15 February 2021.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

GREENING AS LOW-TECH SOLUTION TO IMPROVE BUILDING ENERGY PERFORMANCE – WHAT CAN IT ACHIEVE?

SUMMARY

The research project MARGRET is one of the first projects to quantify greening effects on buildings with modern insulation standards. Five façade greening systems and two roof boxes (green vs. non-green) were tested under controlled conditions. Measurements included surface, air and operative temperatures, heat flow, irradiance and thermal transmission. Plant physiological data such as leaf area index (LAI), water requirements and stomatal conductance were also recorded, as well as local climate data like humidity, wind and solar radiation. Standardized measurement methods and parameters were interdisciplinary discussed to enable implementation of building greening energy benefits in standards and energy performance certificates.

Key words:
vertical greening, green roof, green infrastructure, shading, cooling, MARGRET, energy performance certificate, standardized data, low-tech solution, microclimate, climate change adaptation

INTRODUCTION

Greenery on buildings acts like a natural air conditioning system: they reduce the heating of façades and roofs, cool through evaporation and additionally provide a habitat for flora and fauna. Beyond their impact on individual buildings, green façades and green roofs are key measures for mitigating urban heat. Consequently, many cities have implemented roof and façade greening as important components of their climate adaptation strategies. The current EU Climate Change Adaptation Strategy 2021 strongly favors the promotion of nature-based solutions in the form of "green roofs and external walls" (Art. 11). Nevertheless, planners and building owners currently lack the possibility of quantifying the influence of green infrastructures on buildings. Because of this, these benefits can't be included in official documents like the Energy Performance Certificate. Despite many international studies on the positive effects of greening, there is currently no comparable data on greening effects in the context of modern building thermal insulation standards. A lack of standardized test procedures and non-comparable thermal standards in measured buildings make the development of valid performance indicators very difficult.

The research project MARGRET, a collaboration between research institutes AEE INTEC, IBO, GRÜNSTATTGRAU, and BOKU, performed empirical studies on vertical greenery and green roofs. The AEE INTEC façade test box, as seen in **Fehler! Verweisquelle konnte nicht gefunden werden.** (left), providing modern insulation standards and uniform conditions for the test and reference room, allows for comparative measurements on vegetated an non-vegetated façades under identical conditions. Five different façade greening systems on mobile frames were examined. In addition, two identical roof test boxes, with OIB-conform insulation standards, were built to measure the effects of a green roof in comparison to a non-greened roof.



FIG. 2:
LEFT: FAÇADE TEST BOX AT AEE INTEC WITH LIVING WALL AND REFERENCE FAÇADE;
RIGHT: GREEN ROOF TEST BOX, REFERENCE GRAVEL ROOF IN THE BACKGROUND. © MARTINA MAJCEN, AEE INTEC

OBJECTIVES AND METHODS

The project had three main objectives:

1. The development of methods for measuring the impact of greening on greened versus non-greened reference objects with contemporary building standards under standardized framework conditions.
2. Carrying out measurements on greened and identical non-greened buildings to record the effects of greening buildings, identify the significant parameters and create reference values.
3. Preparation of recommendations for adaptations to the calculation models and standards that promote the implementation of building greening (e.g. energy performance certificate).

Five different façade greening systems on mobile frames were examined: 4 through-bound greeneries with *Parthenocissus quinquefolia var. engelmannii* or *Wisteria sinensis* on climbing frames, one with and one without window shading, and a living wall system (see Fig.1). The test rooms of the façade test box are thermally decoupled and have identical façade dimensions and window openings. One of the two identical test roofs was covered with a standard "reduced intensive" green roof (15 cm single-layered substrate), while the other was covered with gravel. A wide range of building physical and microclimatic effects were measured over two summer and one winter season: surface and air temperatures, heat flow, radiation transmission, influence on cooling energy demand, and outdoor microclimatic changes. At the same time, plant physiological parameters were recorded to derive correlations between plant condition and effects, e.g. degree of plant coverage, leaf area index (LAI), stomatal conductance (g_s), transmissivity and plant volume. A web-based digital twin with real-time integration of measurement data was set up to enable location-independent tracking and data visualization for the whole project team.

RESULTS AND CONCLUSIONS

The main results demonstrate a significant reduction in surface temperatures both behind vertical greening systems as well as on green roofs compared to non-greened reference surfaces. On hot summer days, the gravel roof's surface reached temperatures up to 61 °C (at max. air temperature of 32°C), while the green roof remained much cooler at a maximum of 39 °C—a temperature reduction of 22 °C. Even when applied to a roof built to modern insulation standards (U=0,199 W/m²K), a significant reduction of heat flows into the building was observed (see Fig. 3). In addition, the pronounced reduction in diurnal temperature fluctuations, is likely to have a positive effect on the service life of roof components, particularly the waterproofing layer.

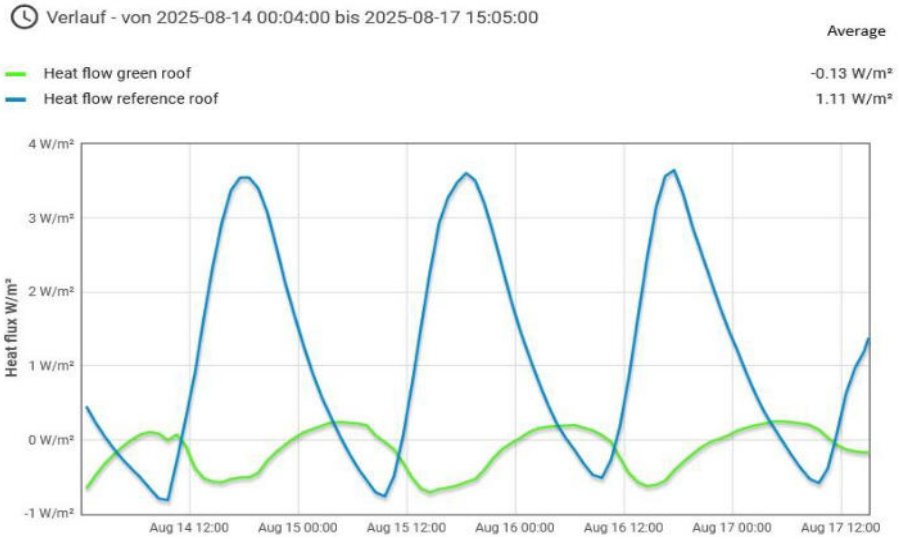


FIG. 3: HEAT FLOW THROUGH GREEN VS. NON-GREEN ROOF ON HOT SUMMER DAYS © AEE INTEC

Vertical greening systems can reduce solar irradiance on the building envelope by roughly 75% compared to uncovered facades, depending on the density of the leaf cover. Correspondingly, the maximum diurnal surface temperature rise of external walls is significantly reduced. However, the impact on transmissive energy losses is less significant compared to green roofing systems. “Bioshading”, i.e. vegetated layers in front of windows can reduce solar irradiance as effectively as conventional shading systems, while also providing additional benefits such as reduced outdoor surface temperatures, evaporative cooling, fine dust binding, and habitat creation. Beyond the irradiation studies, albedo values of the green walls were determined, providing important input parameters for building energy and microclimate simulations.

Principles for incorporating greenery into energy performance certificates have been developed. For example, the shading from green walls can now be calculated and factored in on a monthly basis. The measured impacts of green roofs could justify reducing the thickness of conventional insulation materials once incorporated into relevant standards. Green structures thus represent a robust ‘low-tech’ solution supporting climate change adaptation and energy savings. A comparison with standards such as ÖNORM L1136 (vertical building greening) will be carried out to establish appropriate supplements.

TOWARDS POSITIVE ENERGY DISTRICTS – HEAT PUMP SYSTEM TOPOLOGY DESIGN GUIDELINES

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SUMMARY

A Positive Energy District (PED) envisions supporting the urban energy transition, requiring improved technologies and holistic planning processes. “Campagne” project in Innsbruck serves as a demonstrator on the path towards PEDs. Multiple heat pump (HP) system topologies can be considered, ranging from fully central HP systems at district scale to semi-central solutions with a central low-temperature HP and booster HPs at building or flat level, as well as decentral building-wise HPs and mixed concepts such as central for space heating and decentral for domestic hot water. The optimal HP system topology depends on local boundary conditions, with decentral HPs generally outperforming central ones. Semi-central booster configurations achieve good energy performance but remain economically challenging, highlighting the need for decision-support workflows that enable cost-optimal design and serve as the basis for a future integral planning approach.

INTRODUCTION

With the goal to support the energy transition in cities Positive Energy District (PED) can serve as a vision and support to improve technologies and the planning process (Ochs et al. 2025). A net positive energy balance is possible for new highly efficient buildings with efficient heat pump (HP) systems and on-site Renewable Energy (RE) even in cold climates. However, reaching PED in existing or in high-density districts on the footprint can be very challenging. Furthermore, the planning of HP systems for PEDs is far more complex due to significantly higher degree of freedom of design. Different energy needs on different temperature levels such as space heating (SH), domestic hot water (DHW) and space cooling have to be considered. Depending on the load profile, which is a function of the type of building (residential, non-residential) and the climate and the HP source availability on site (or nearby) different HP system design and integration options are available:

- Central (one per district)
- Semi-central (central low temperature HP + decentral booster HP on building or flat level)
- Decentral (building-wise HP)
- Mixed (e.g. central SH, decentral DHW)

HP DESIGN WORKFLOW

A design workflow for HP systems for PEDs considering local boundary conditions (source availability and temperature) and constraints such as space limits or sound emissions is presented. The design workflow follows the cost-optimality approach as suggested by the EPBD. HP system design variables are schematically shown in Fig. 1.

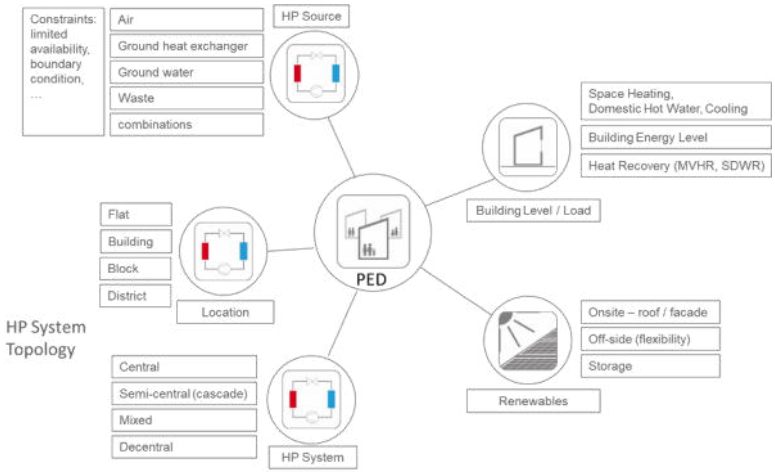


Fig. 1: HP System Design Variables

RESULTS

Figure 3 shows the annual electrical energy demand and total annual (gros) costs of the different HP system topologies for the "towards" PED Innsbruck Campagne (Ochs et al. 2024):

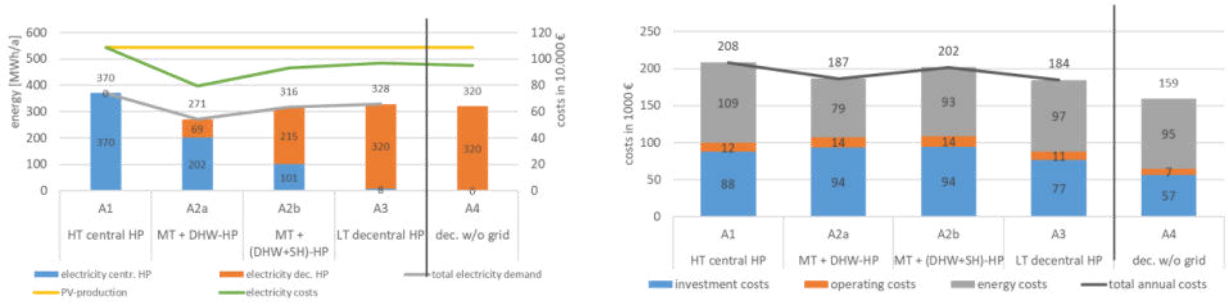


Fig. 3: Annual electrical energy demand and total annual (gros) costs of the different HP system topologies (A1: central HP with high temperature distribution, A2a: Semi-central (medium T) with flat-wise return flow HP, A2b: Semi-central with building-wise booster HP A3: low T distribution with building-wise HP, A4: individual HPs)

SUMMARY AND OUTLOOK

Central systems with presumably lower invest costs compete with decentral HPs that feature generally the best system performance (lowest thermal losses, best HP performance). In PEDs with an inhomogeneous building structure decentral booster HPs that allow for lower distribution temperature could be interesting. The proposed workflow can support decision-making and can serve as a basis for a future integral planning approach for PEDs. As examples three different case studies from Germany (Quarree100), Austria (Campagne) and Switzerland (Papieri) are presented.

REFERENCES

Ochs, F., Tosatto, A., Venturi, E., Breuss, S., Magni, M., Dermentzis, G., Wemhoener, C. (2024). Characteristic load curves of positive energy districts, Solar Energy Advances, Volume 5, 2025, 100081.
Ochs, F., Breuss, S., Venturi, E., Magni, M., Dermentzis, G. (2024). Towards Positive Energy Districts: Innsbruck, "Campagne Areal". International Sustainable Energy Conference - Proceedings, 1.

CONFERENCE TOPIC

1.16. Transform Cities: Holistic Approaches to Sustainable Urban Energy

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THERMALLY ACTIVATED BUILDING SYSTEMS IN TIMBER STRUCTURES

SUMMARY

Thermally Activated Building Systems (TABS) are increasingly applied in concrete structures, where they have become an established solution for energy-efficient heating and cooling. For this purpose, a metrological investigation and optimisation of thermal component activation (TABS) of solid wood building components, their heat emission and absorption is carried out. The energy demand and efficiency as well as the heating and cooling performance of the TABS and the influence of the covering in terms of covering thickness and material are investigated as well as the energy flexibility through storage of the energy in the building components. In timber constructions applications remain rare despite their significant potential. The research focuses on the design, construction methods, and monitoring of a multi-storey residential demonstration building in Salzburg. Special emphasis is given to the thermal storage potential, the long-term behavior in heating and cooling operation, and moisture safety aspects. The findings aim to provide a blueprint for broader application of TABS in timber buildings, contributing to decarbonisation, resource efficiency, and improved indoor comfort.

Keywords: Thermally Activated Building Systems (TABS), thermal storage, energy flexibility, climate-neutral buildings

MAIN SECTION

Due to the climate and energy crisis, the construction industry is facing challenges such as the creation of housing in urban areas or the reduction of CO_2 emissions and energy consumption of living space in urban areas or the reduction of CO_2 emissions and energy consumption. The decarbonisation of the building sector requires innovative solutions that combine renewable energy integration with efficient building systems. While TABS in concrete are well established, the use of activated timber elements remains underdeveloped. Recent simulation and laboratory-scale studies indicate that CLT with integrated pipe systems and heat distribution layers can provide thermal storage capacities comparable to concrete slabs. During system development, initial simulations were carried out to determine the required areas for component activation and room temperature control, taking into account the exposure area. This was based on a previous research project "aHolz" (Heidenthaler, D., Leeb, M., Schnabel, T. & Huber, H. 2021) and the master's thesis by Daniel Heidenthaler (Heidenthaler, 2020), which investigated component activation in cross laminated timber. Component simulations were subsequently carried out with the help of the calculation and simulation programme HTflux (version 1.10). HTflux creates high-resolution, two-dimensional simulations of heat and moisture transport in building components and was used for variant studies on flow temperatures, which is shown in Figure 1.

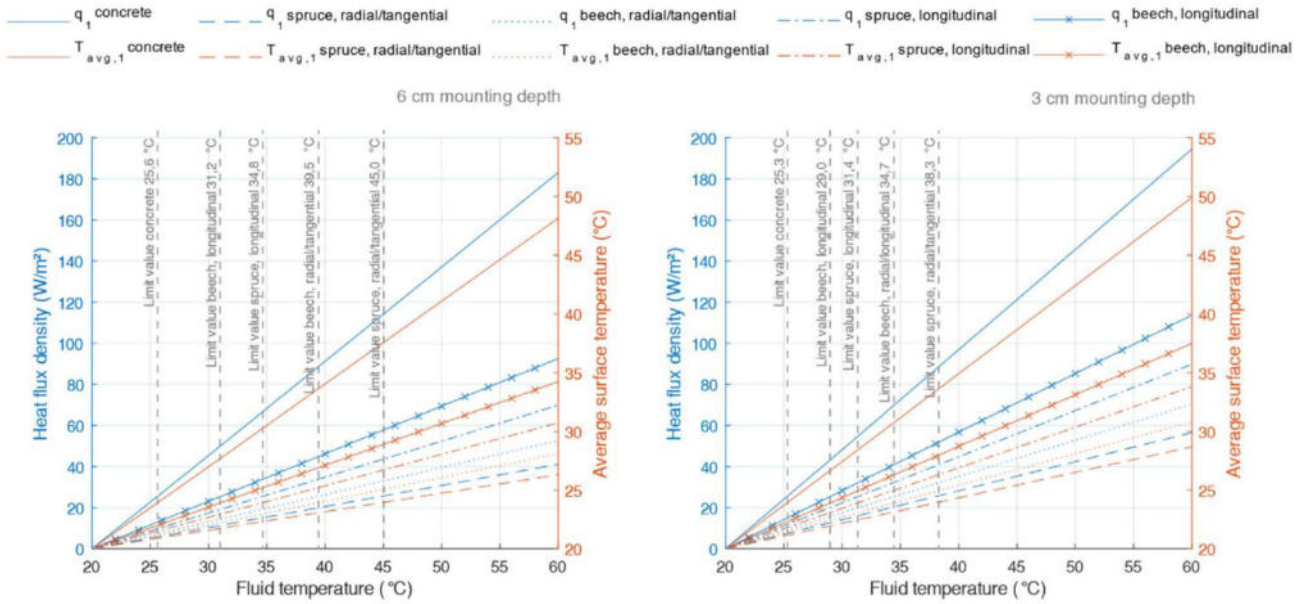


Fig.1. Comparison of heat flux density and average surface temperature as a function of the fluid temperature for a mounting depth of 6cm (left) and 3 cm (right) for TABS in concrete and wood shown in (Heidenthaler, D., Leeb, M., Schnabel, T. & Huber, H. 2021)

Figure 1 shows the comparison of different materials to a defined heat flow of 26 W/m² and the and the required pre-flow temperature.

Based on the simulation results, a prototype of wood activation with heat conduction fins was developed and built, which was tested in heating and cooling mode on the Twin²Sim facade test rig within a multifunctional building envelope.

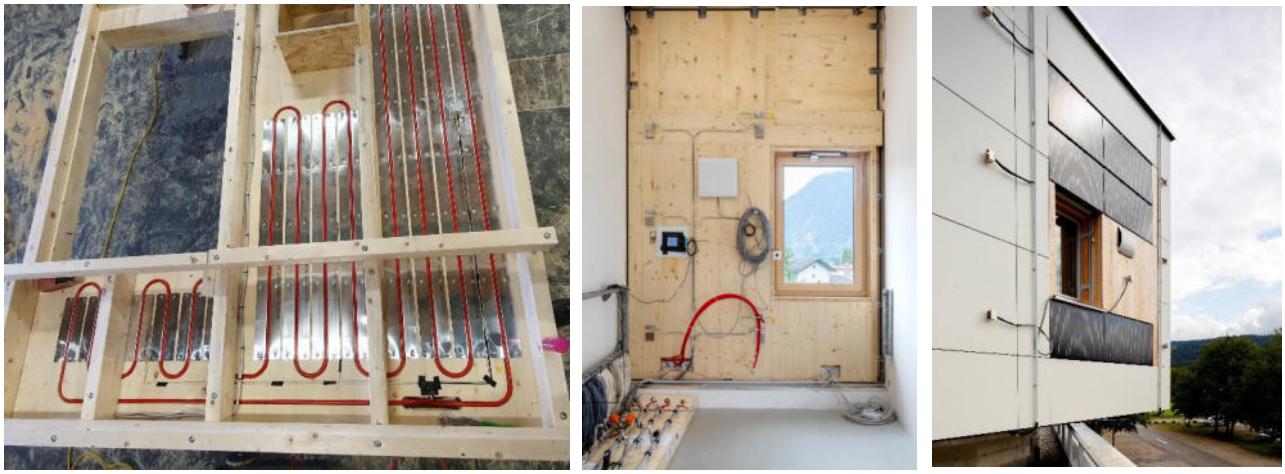


Fig.2. Construction of wood activation with heat conduction fins, interior view of wall activation, and exterior view of the element with integrated photovoltaics.

For wood activation, tests were carried out in heating and cooling mode with different flow temperatures in order to measure the heat flow, surface temperature, and component moisture.

Evaluations of heating and cooling tests have shown that, depending on the flow temperature and room temperature, the following heat flows can be achieved with wall activation using heat-conducting fins and a 42 mm 3-layer spruce panel covering.

Cooling case: Room temperature 22.7 °C
Flow temperature 16 °C - Measured cooling flow 9 W/m²
Flow temperature 20 °C - Measured cooling flow 4,6 W/m²
Heating case: Room temperature 22.2 °C
Flow temperature 30 °C - Measured heating flow 8,3 W/m²
Flow temperature 40 °C - Measured heating flow 21,4 W/m²

In addition, the heating and cooling behavior of thermal component activation in wood was measured, allowing conclusions to be drawn about its storage capacity. Previous experiments showed that activated CLT elements can achieve usable storage potentials of up to 530 Wh/m², close to the values of concrete slabs, but within higher preflow temperatures ut to 45°C.

The demonstration project with 12 apartments will validate these results under real building conditions. In addition to thermal performance, the study will analyse moisture behaviour during cooling operation – a critical aspect for timber safety.

The demonstration building in Salzburg within 12 flats integrates thermally activated CLT slabs in its upper floors. Different construction variants are compared, including:

- Pipe integration techniques (CNC-milled grooves in CLT with heat distribution lamellas)
- Variation of cover layers regarding fire safety, acoustic and visual requirements
- Operational strategies for energy-flexible heating and cooling

Monitoring includes surface and core temperatures, moisture sensors, and indoor climate measurements to evaluate both energy and comfort performance. Simulation studies accompany the monitoring to assess scalability and life-cycle impacts.
This opens the path towards lightweight, renewable-based construction methods with integrated energy systems.

CONFERENCE TOPIC

Renewable Heating and Cooling Solutions
Coupling of Energy Sectors
Sustainable Renovation and Energy Retrofits

REFERENCES

Heidenthaler, D. (2020). Bauteilaktivierung im Holzbau - Untersuchung der Funktionstauglichkeit anhand einer Parameterstudie [Master's thesis]. Salzburg University of Applied Sciences, Salzburg.

Heidenthaler, D., Leeb, M., Schnabel, T. & Huber, H. (2021). Comparative analysis of thermally activated building systems in wooden and concrete structures regarding functionality and energy storage on a simulation-based approach. Energy, 233, 121138. https://doi.org/10.1016/j.energy.2021.121138

A SHOWCASE OF SERIAL RENOVATION WITH INTEGRATED TECHNOLOGIES

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SUMMARY

This abstract presents one of three large-scale serial renovation demonstrators within the Austrian flagship research project RENVELOPE. The Viennese case study integrates a façade-embedded building activation system into prefabricated timber-frame façade elements, combined with model predictive control (MPC) and a hybrid renewable energy supply. This approach enables deep renovation without the need for occupant relocation, while addressing both building envelope performance and energy supply in a single intervention. Dynamic simulations project a reduction of over 80 % in final energy demand and associated CO_2 emissions, achieved by replacing the existing fossil gas heating with low-temperature heat pump systems powered by on-site photovoltaic generation. The project aims to demonstrate a technically feasible, scalable and occupant-friendly pathway for the rapid decarbonisation of the residential building stock.

ARENBERGGASSE 4, VIENNA

The key research question is whether Arenberggasse 4 in Vienna is suitable for a building activation system in combination with a Model Predictive Control (MPC) software and what are the predicted energy savings of the building after the renovation.

Background Information: Arenberggasse 4 is a residential building located in an urban area of Vienna. Constructed in 1977, the building comprises seven storeys, with a total volume of 5,637.1 m³ and a gross floor area of 2,019.2 m². It was originally built using concrete wall construction (no thermal insulation was installed) and operated entirely on a gas-based energy system for both heating and domestic hot water. The building's original thermal performance included a theoretical U-value of 1.16 W/m²K, a specific heating energy demand of 89 kWh/m²a, and an estimated CO_2 output of 41 kg/m²a, based on local climate conditions.

The **Simulation**: The software used for the simulations were HT Flux for the heat transfer coefficient (HTC) (see exemplary image in Figure 1) and IDA ICE, within which a model of the building (see Figure 2) was constructed including all detailed information on its materials, and the previously calculated HTC for the existing wall. IDA ICE enables a dynamic simulation of the building's thermal behaviour, helping to better understand how newly added façade systems respond to changing environmental conditions. It provides insights into the thermal and operational characteristics of various building components in a realistic and time-dependent context. Additionally, it supports the testing and refinement of heating and cooling strategies using advanced control methods, such as MPC. These capabilities make it a useful tool for evaluating design choices and improving overall building performance. The simulation results showed that the supply temperature of the thermal media in the façade would not have to exceed 45 °C at the coldest outside temperature conditions. This result means that the building is well suited to an external building activation system in combination with renewable energy sources.

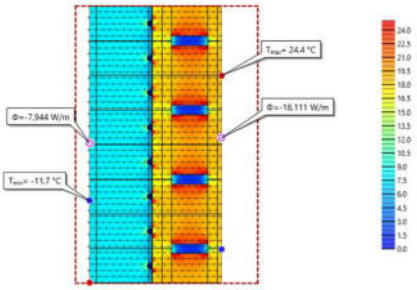


Figure 1: Heat Transfer Modelling with HT Flux



Figure 2: Model of the Arenberggasse 4 for IDA ICE

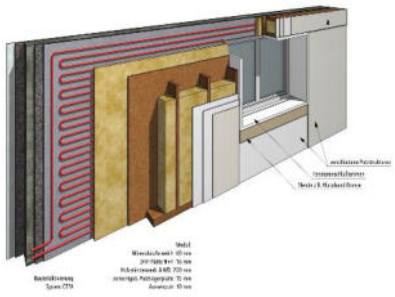


Figure 3: Façade element layers

The **Renovation Plan**: Following the simulation results, key components of the serial renovation strategy include the integration of a building activation system within prefabricated façade elements, specifically using the building activation system CEPA system (see Figure 3 Façade element layers) which will be regulated by an MPC software, as well as electrical solar shading and the replacement of select windows with larger French-style windows. The attic floor and the cellar ceiling will also be insulated and receive a building activation system, so that the building activation system is not just reliant on the façade area. In addition to the thermal envelope, the roof will be equipped with a photovoltaic system (18 kWp). For heating and domestic hot water, a hybrid system combining air-to-water heat pumps and ground source heat pumps (via two boreholes in the courtyard) will replace the previous gas system. With these measures, the theoretical energy requirement for the building will be reduced by over 80 %. All building users are onboard with and approving of the renovation process.

The **Execution Phase**: The renovation will begin in September 2025, with installation of the new façade panels in October 2025. The completion of works will be completed by the end of the year, demonstrating the speed and efficiency of the serial renovation process. This compressed renovation schedule is of particular research interest, as it demonstrates the potential of serial renovation to minimise disruption for occupants and to accelerate the large-scale implementation of deep energy retrofits required to meet climate targets.

CONCLUSION: THE SIGNIFICANCE OF THE RENVELOPE-DEMONSTRATORS AND FURTHER RESEARCH QUESTIONS

The RENVELOPE demonstrator provide a proof of concept thattechnology driven serial renovation can be achieved efficiently and without interrupting the building's use, while reducing the building's energy consumption over 80 %. They highlight the potential of integrating advanced technologies directly into prefabricated façade elements, streamlining the construction process and the energy upgrade and enabling energy optimisation through MPC. Crucially, these projects show that acting on climate goals does not come at the expense of occupant comfort; on the contrary, the renovated buildings offer higher living standards and better indoor climate conditions.

Further key questions remain open for evaluation of the buildings and the findings will also be presented at the conference:

- Was the renovation timeline adhered to?
- - Does the integrated building activation system perform as expected?
- - What is the actual post-renovation energy performance?
- -How do residents perceive the changes in comfort and building use?

Post-renovation monitoring and occupant surveys will provide the data to address these questions.

Conference Topic: "Sustainable Renovation and Energy Retrofits"

ENERGY AND GREENHOUSE GAS EMISSION SAVINGS THROUGH SERIAL RENOVATIONS BY APPLYING THE RENVELOPE SYSTEM IN AUSTRIA

Dr Alexis Mundt; Dr. Wolfgang Amann (IIBW) & Florine Leighton (AEE Intec)

SUMMARY

To achieve international and national energy and greenhouse gas emission targets, Austria requires rapid and scalable renovation methods for existing buildings. A comprehensive consortium is currently exploring the potential of serial renovations using the RENVELOPE-system in a research project. This paper presents preliminary findings on the number of eligible buildings in Austria and the potential energy and greenhouse gas emission reductions that could be achieved by renovating these buildings. First, we developed a model based on Austria's current building stock. Then, we calibrated parameters based on the energy sources used and the qualities of the building envelopes after renovation. Our findings indicate that the potential for serial renovations in Austria is substantial, with around 71,500 buildings potentially benefiting from RENVELOPE renovations. By renovating these buildings, the base scenario predicts a 73% decrease in final energy demand (heating, warm water, and electricity) and a 75% decrease in CO_2 emissions. Our results emphasize that technological advances, particularly those that reduce the cost of prefabricated modules and enable the integration of renewable energies, as well as political adjustments, such as subsidy programs or changes to the legal framework (e.g., building and tenancy laws), can further increase this potential.

Key words: Serial renovations, greenhouse gas emission savings, energy savings, renovation of the building stock, new technologies, potential, Austria

INTRODUCTION

The climate targets set at the international and national levels clearly indicate that a significant amount of energy and CO_2 savings can be achieved by upgrading the existing building stock to a sufficiently high standard through a massive wave of renovations. In Austria in particular, efforts to date must be greatly expanded. This paper examines the potential of serial renovations of existing buildings in Austria to contribute to this effort.

The potential of serial renovation is explored by the Austrian flagship project RENVELOPE (2025) through the integration of building technology into façades, with the aim of achieving energy, economic, and social benefits. The project's research focuses on prefabricated façade modules that incorporate insulation, windows, and roofing elements and are mounted directly onto existing structures. This method of serial renovation is called the RENVELOPE-system. Coordinated by AEE INTEC, RENVELOPE is funded by the Austrian Climate and Energy Fund as part of the "Vorzeigeregion Energie" program, in collaboration with Green Energy Lab. The project unites over 18 research institutions, industry partners, and property management firms to develop scalable façade solutions applicable in Austria and beyond. This contribution is part of ongoing research within the RENVELOPE project. The final results of the entire project will be made public in March 2027. However, since the research questions on which this contribution is based formed the foundation for future work packages within the entire research project, the results presented here are largely finalized and have undergone several plausibility checks by internal and external experts (IIBW & AEE Intec, 2025). This contribution focuses on estimating (1) how many and which buildings in Austria are currently suitable for RENVELOPE refurbishments and (2) the energy and greenhouse gas emission savings that can be achieved by renovating these properties.

METHODS

In assessing the potential for implementing RENVELOPE renovations in Austria, we first identify the most suitable buildings. Our investigation is based on the most current extract of the building register, and we analyze Austrian buildings using indicators such as building decade, number of stories, and building use. Through a bottom-up research approach and together with construction and building experts, we identify technological hurdles for RENVELOPE renovations depending on building type. We then assess the most suitable buildings by applying a set of key performance indicators. We exclude buildings that have undergone comprehensive renovations of sufficient quality in the last two decades. We also consider factors such as unsuitable building volumes, Austrian fire safety requirements, and difficulties with in-situ installation of necessary prefabricated modules. Through this consecutive, multi-step procedure, we identify buildings that are the most suitable for the RENVELOPE system.

In a second step, we estimate the potential savings in final energy and greenhouse gas emissions if the identified properties were renovated using the RENVELOPE system. We calibrate the relevant parameters of our models using several sources, including the parameters used by the Austrian Environment Agency (UBA) in their yearly calculations of energy savings through housing subsidies in Austria; the parameters used in the OIB guidelines ("Österreichiches Institut für Bautechnik") and in the calculation of energy performance certificates; the Vorarlberg Energy Institute's (EIV) estimates of energy consumption after renovations; expert opinions generated by the Delphi method; and the literature. Depending on the quality of the building envelope, the primary energy source used (ideally heat pumps, district heating systems, or biomass), and the photovoltaic potential after renovating a given building, we can calculate different scenarios. By assessing these scenarios and defining the most likely pathway, we calculate the range of potential energy and greenhouse gas emission savings.

RESULTS

We find that Austria has a high potential for serial renovations and that around 71,500 buildings could benefit from RENVELOPE renovations. In the most likely scenario, renovating these buildings could decrease their final energy demand by around 73%. CO_2 emissions would decrease by 75%. This corresponds to a total CO_2 emission reduction of 1.8 to 2.1 million tons, a significant portion of the emissions currently produced by the building sector. By calculating different scenarios, we develop ranges for these estimates. Our results emphasize that technological advances, particularly those that reduce the cost of prefabricated modules and enable the integration of renewable energies, as well as political adjustments, such as subsidy programs or changes to the legal framework (e.g., building and tenancy laws), can significantly increase the potential.

REFERENCES

IIBW & AEE Intec (eds.) (2025), RENVELOPE-Sanierungen. Potenzialanalyse für Österreich. Im Rahmen des Forschungsprojekts RENVELOPE – Energy Adaptive Shell Konsortialführung AEE INTEC Gefördert im Rahmen der FTI-Initiative „Vorzeigeregion Energie" (FFG-Nr. 894534), Vienna: IIBW.

RENVELOPE (2025), RENVELOPE Energy Adaptive Shell. Komplettlösung für die serielle Gebäudesanierung und integrierter Energieversorgung. Research project homepage: www.renvelope.at [3.9.2025].

NEW BUSINESS AND FINANCING MODELS TO ENABLE INDUSTRIALISED RENOVATIONS: ESCOS AND CROWDFUNDING

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SUMMARY

Industrialised construction and innovative financing are both necessary to accelerate deep building renovations in Europe. However, industrialised methods face a cost-competitiveness barrier versus conventional approaches. This abstract presents insights from the LIFE BuildUPspeed project and argues that new business and financing models—centred on ESCO-led Energy Performance Contracts (EPCs) and lending-based crowdfunding—can close financing gaps, reduce perceived costs, and enable wide-scale adoption of industrialised renovation solutions. Examples include Market Activation Platforms (MAP) and Pop-up Factories (PuFs) as enablers of technical scalability and contextual adaptation, with crowdfunding supporting both EPCs and PuFs to make industrialised renovation financially viable.

Keywords: Industrialised construction, ESCO, crowdfunding, EPC, sustainable renovation

INTRODUCTION

Europe's construction sector is undergoing a strategic transformation driven by the Green Deal and the Renovation Wave. Industrialised construction offers tangible advantages—faster delivery, reduced waste and emissions, improved quality control, and enhanced energy performance—but widespread uptake is constrained by perceptions and realities of higher upfront costs compared to conventional methods. Simultaneously, energy efficiency renovations remain capital-intensive, deterring many property owners despite attractive long-term paybacks.

The LIFE BuildUPspeed project focuses on unlocking European R&I outputs for market uptake by aligning industrialised solutions with real-world renovation needs. This work examines how bespoke business and financing models, combining ESCO-led EPCs with crowdfunding, can bridge the gap between technical innovation and market reality, making industrialised renovation financially competitive and scalable. Crowdfunding can also finance Pop-up Factories (PuFs), helping to reduce CAPEX and enabling faster, wider adoption of industrialised renovation solutions.

METHODOLOGY APPROACH

The analysis combines descriptive synthesis of BuildUPspeed outputs (**MAP** and **PuF scenarios**) with a conceptual business-model framework and an illustrative financial example. The methodological steps are:

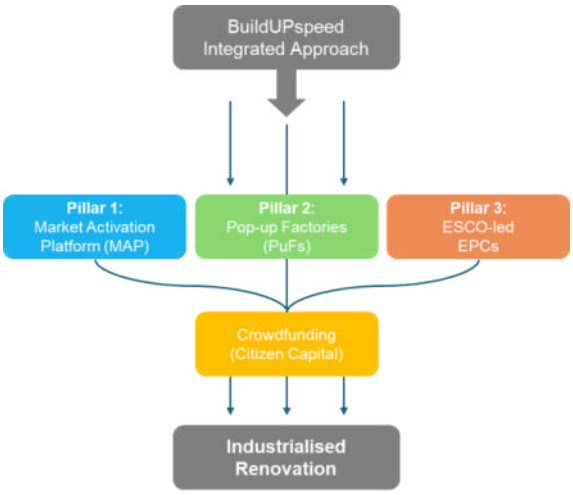
- Review and synthesis of BuildUPspeed tools: **Market Activation Platform (MAP)** and **Pop-up Factory (PuF)** concepts and scenarios.
- Development of a modular business-model framework integrating **ESCO-led EPCs** with **lending-based crowdfunding** to co-finance CAPEX, support Pop-up Factories, and engage stakeholders.

- Construction of an illustrative financial scenario to demonstrate CAPEX sharing, potential payback, and implications for investor engagement and social acceptance.
- Discussion of policy levers and operational measures required to de-risk these models and facilitate replication across EU contexts.

RESULTS AND DISCUSSION

BuildUPspeed provides two complementary tools that address technical and market barriers:

- **MAP (Market Activation Platform) consolidates industrialised solutions, technical data, and case studies, helping decision-**makers **select context-appropriate approaches that respect digitalisation and circularity criteria.**
- **PuFs (Pop-up Factories) enable localised, modular production near renovation sites, reducing transport, allowing real-time customisation, and facilitating economies of scale for medium-term renovation campaigns.** Crowdfunding **can support PuFs directly, reducing CAPEX and fostering local engagement.**
- **Business-model integration:** ESCOs can package technical services and offer EPCs that transfer performance risk from owners to providers, while lending-based crowdfunding platforms mobilise citizen capital to co-finance a share of CAPEX, including for PuFs, and foster local acceptance. When combined with MAP and PuFs, this integrated model strengthens both technical feasibility and financial competitiveness.



CONCLUSIONS

Industrialised construction can materially support Europe's decarbonisation and renovation objectives, but technical innovation alone is not enough. New business and financing models are essential to close the cost gap with conventional construction and to scale industrialised solutions. The LIFE BuildUPspeed approach—by combining MAP and PuFs with ESCO-led EPCs and lending-based crowdfunding—offers a promising pathway to unlock market uptake. Crowdfunding can finance both EPCs and Pop-up Factories, helping to reduce CAPEX and enabling faster adoption of industrialised renovation solutions.

Policy support that clarifies contract standards for EPCs, enables safe citizen investment via crowdfunding, and funds PuF pilots will accelerate the transition. Future work will pilot integrated ESCO–crowdfunding contracts alongside PuF deployments and expand MAP case libraries to demonstrate replicable, bankable models across diverse EU markets.

REFERENCES

BuildUPspeed (2024). Accelerating the Construction in Europe. https://buildupspeed.eu/news/buildupspeed-accelerating-the-construction-in-europe/

CONFERENCE TOPIC

Financing and Policies for Energy Efficiency in Buildings

PARETO REFURBISHMENT EVALUATION FOR ENERGY FLEXIBILITY

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SUMMARY

The energy-efficient and climate-neutral renovation of residential buildings is a key challenge of the energy transition, often hindered by time, budget, and user acceptance. The FluccoSan project introduces a holistic concept for dynamic renovations, focusing on achieving 80% of energy and ecological benefits with just 20% of the effort. The interactive tool LevelUp guides users through three modules: preference weighting, interactive decision trees, Pareto Index calculation and visualization of the results. Users assign weights to energy efficiency, ecological impact, economic viability, needed effort and user acceptance, while decision trees evaluate the relevant parameters. The Pareto Index identifies optimal measures for the renovation and visualizes top-performing options. The tool provides a transparent, data-driven comparison of renovation measures, including projections for energy savings, CO_2 reductions, costs, effort and comfort. This approach enables step-by-step, user-friendly renovations, contributing to sustainable, energy-flexible, and circular building transformations.

INTRODUCTION

Addressing the energy-efficient and climate-neutral renovation of residential building stands as a central challenge of the ongoing energy transition. Residential buildings account for almost 30% of the global energy consumption and greenhouse gas emissions, making their sustainable transformation a key priority (IEA, 2025). The new buildings directive of the European Commission now states that until 2050 16% of all buildings need to be refurbished (European Comission, 2024). While deep renovation strategies aim for comprehensive, one-time interventions to maximize energy efficiency and reduce emissions, practical constraints such as time, budget, and user acceptance often limit their feasibility. Furthermore, the potential for energy flexibility in existing buildings remains largely untapped. This is a missed opportunity, as energy flexibility could play a crucial role in stabilizing energy grids and integrating renewable energy sources. Simultaneously, the principles of the circular economy and end-of-life planning are gaining importance to address resource usage and environmental impacts in a sustainable manner. These challenges call for innovative approaches that balance energy efficiency (E), ecological impact (L), time and effort (T), economic viability (C), and acceptance (A).
In the FluccoSan project, a holistic evaluation concept for dynamic renovation strategies is developed that focuses on identifying and implementing low-hanging fruits. The goal is to achieve 80% of the energy and ecological benefits with just 20% of the total effort, thus called pareto refurbishment, thereby making renovations more accessible and scalable. This approach is particularly relevant for existing buildings, where incremental improvements can often yield significant benefits. The technical foundation for this concept is the interactive energy consulting tool LevelUp, which guides users through a structured decision-making process using three coordinated modules. These modules are designed to ensure that renovation measures are not only effective but also tailored to the specific needs and preferences of users.

PREFERENCE WEIGHTING

The first module allows users to assign individual weights to five key dimensions: energy efficiency and flexibility (W_E), ecological impact like life cycle assessment (W_L), economic viability or costs (W_C), needed

effort and time for the refurbishment (W_T) and user acceptance (W_A). These weights reflect the user's priorities and ensure that the evaluation process is customized whereas the sum of all weights must accumulate to 1.
This step ensures that the evaluation framework is adaptable to different stakeholder's needs, whether the focus is on energy savings, minimizing environmental impact, reducing costs, or enhancing user comfort.

INTERACTIVE DECISION TREES

The second module employs interactive decision trees for each of the dimensions. These trees systematically query relevant parameters to evaluate renovation measures. For energy efficiency, the primary energy demand is assessed. For ecological impact, projected CO_2 savings are calculated based on life cycle assessment principles. Economic viability is evaluated using cost categories, including investment and operational costs. Finally, user acceptance is measured using comfort Likert scales, which capture subjective preferences and satisfaction levels. This structured approach ensures that all relevant factors are considered in a transparent and systematic manner.

CALCULATION OF THE PARETO INDEX

To make the trade-offs between benefits and efforts comparable, the Pareto Index (PI) is defined as follows:

$$PI = \sum f_i W_i = (E \cdot W_E + L \cdot W_L + A \cdot W_A + C \cdot W_C + T \cdot W_T) \cdot 100\% \quad \text{(eq. 1)}$$

Where E (Energy and flexibility), L (Life cycle assessment), A (Acceptance), C (Costs) and T (Time) represent the normalized values (ranging from 0 to 1) of the linear scalarization determined in the decision trees. A PI > 0 indicates that a renovation measure offers more benefits than compromises, while a PI > 60 indicates that the benefits are 80% of the weighted categories thus making it Pareto-optimal. This index provides a clear and quantitative basis for a multi-objective Pareto-front analysis.

RESULTS AND PRACTICAL IMPLICATIONS

As a result of this process, LevelUp generates a comprehensive tabular comparison of all analysed renovation measures. The table includes the criteria scores determined by user-defined weights, as well as recommendations for minimal, maximal, and Pareto-optimal measures. Additionally, it provides projections for key performance indicators, such as changes in primary energy demand, CO_2 emissions, investment and operating costs, and user comfort. This approach helps to ensure that stakeholders have a clear and transparent basis for decision making. The holistic concept developed in FluccoSan offers significant advantages for planners and property owners. By focusing on dynamic renovation approaches, it enables the gradual transformation of the building stock into energy-flexible, circular, and user-friendly systems. This approach has the potential to reduce the barriers to renovation but also aligns with broader sustainability goals, such as resource efficiency and climate resilience. Moreover, the integration of user preferences ensures that the proposed measures are practical and widely accepted, increasing the likelihood of successful implementation.

REFERENCES

European Comission. (2024, April). *Energy Performance of Buildings Directive*. Retrieved from Energy Performance of Buildings Directive: https://eur-lex.europa.eu/eli/dir/2024/1275/oj

IEA. (2025). *Energy System Buildings*. Retrieved from Inernational Energy Agency: https://www.iea.org/energy-system/buildings

CONFERENCE TOPIC

Sustainable Renovation and Energy Retrofits

DAYLIGHT SIMULATIONS BASED ON A DIGITAL-TWIN MODEL TOWARDS WORKPLACE AND FAÇADE-INDIVIDUAL OPTIMIZATION

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SUMMARY

This work is based on an existing office building, located in Austria, which is equipped with a large number of measurement sensors and is operated as Digital Twin for monitoring purposes. Simulation and research analyses on daylighting and comfort aspects by individual façade control focused particularly on a single floor, which was chosen for its representative characteristics in terms of orientation, spatial distribution, and room utilization.
Initial analyses were performed considering a uniform control of environmental conditions on all facades in order to establish a comparative basis. However, the ultimate goal of the analysis was to elaborate a facade control that could be customized as much as possible by the users of the spaces to ensure a high level of visual and thermal comfort, adaptable to different radiation conditions and individual preferences. Existing monitoring data from the Digital Twin was used to verify the simulation results with state-of-the-art situations.

Keywords: *digital twin, lighting simulation, tools, control strategy, low-carbon high-comfort lighting.*

INTRODUCTION

The growing focus on energy conservation in buildings and the improvement of indoor environmental quality has driven innovation in window design. Complex Fenestration Systems (CFS) often incorporate shading devices alongside high-performance clear glazing to enhance the use of natural daylight and minimize unwanted solar heat gain and glare, which can be problematic with clear glazing alone (Guo, 2014). While CFS generally have great potential to deliver superior performance in terms of thermal transmission, light distribution, and annual energy consumption, an optimal control strategy of such systems is in most operating buildings still a challenging and unsolved situation (Hauer, 2024). Despite the fact, that CFS can create a significant contribution to achieve low-carbon high-comfort buildings by reducing cooling loads and summer overheating, the potential for improvement through suitable control strategies is significant.

DIGITAL-TWIN MODEL

The simulated building was modeled in Rhinoceros 3D (version Rhino 8), where the building geometry was imported based on an IFC, exported from a corresponding BIM-model. The simulations were carried out with Climate Studio, an advanced software platform for daylighting and thermal performance simulation. Climate Studio supports a comprehensive range of environmental analysis workflows, enabling detailed assessments of energy efficiency, indoor lighting quality, and thermal comfort.
The south-west façade is characterized by a division into six large windows, organized in regular modules, which provide direct and diffuse sunlight and continuous views to the exterior. The south-east facade, on the other hand, is divided into 7 large windows.
Subsequently, analyses were conducted by means of simulations, implementing a façade segmentation system. This approach allowed a more precise control of the solar shading system, enabling the precise adjustment of shading at individual workstations.

Modelled office building:

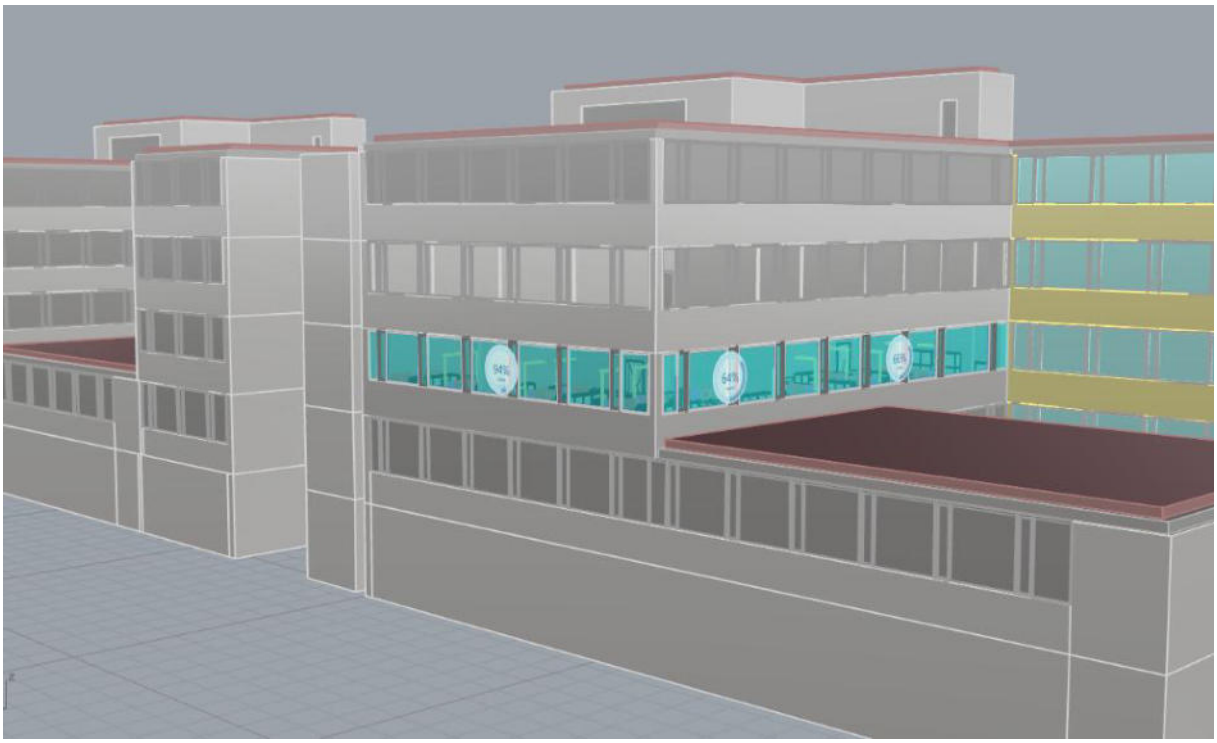


FIGURE 6: 3D MODEL OF THE MODELLED OFFICE SPACE WITH THE RELEVANT FAÇADE SECTIONS IN BLUE

EVALUATION EXAMPLES AND RESULTS

A variety of simulations were conducted, each tailored to produce specific outputs aligned with the visual and thermal performance goals. The analyses covered aspects such as natural daylight availability (useful daylight autonomy, spatial daylight autonomy), luminance distribution (glare evaluations from the different user viewpoints), solar heat gains (annual kwh), and seasonal thermal behavior (overheating frequency), with the aim of optimizing façade-individual control strategies of the CFS and enhancing the overall workplace-individual environmental comfort.

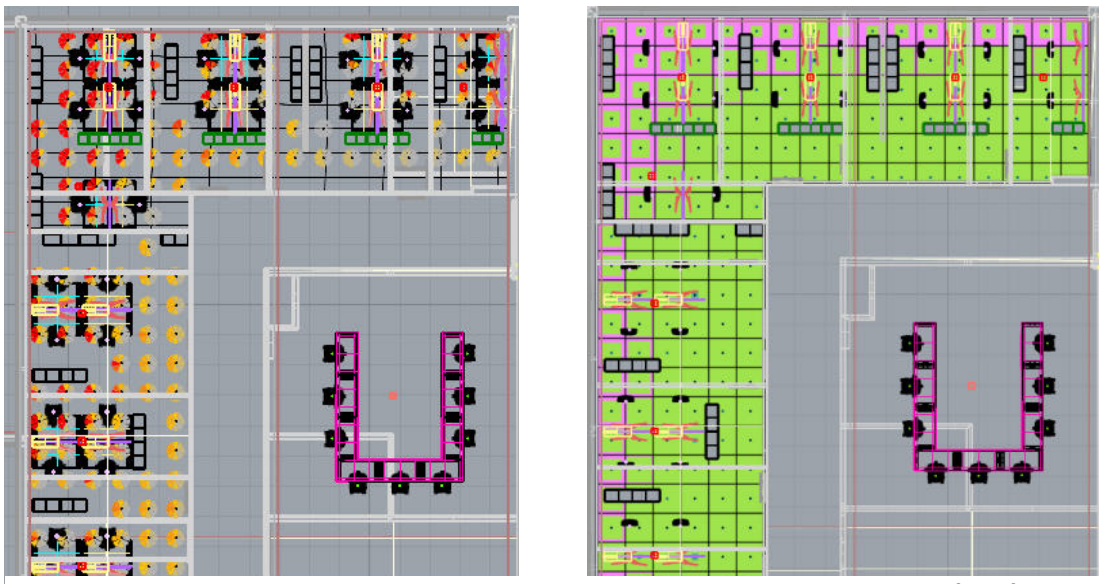


FIGURE 7: EXAMPLE RESULTS FOR A FLOOR-PLAN GRID IN ANNUAL GLARE EVALUATION (LEFT) AND ILLUMINANCE DISTRIBUTION (RIGHT)

REFERENCES

Guo, X., Tian, Z., Zhao, Y., Geisler-Moroder, D., & Hauer, M. (2024). Enhancing indoor light and thermal performance with micro-prismatic materials in complex fenestration systems: A review. Energy and Buildings. https://doi.org/10.1016/j.enbuild.2024.115002.

Hauer, M., Hammes, S., Zech, P., Geisler-Moroder, D., Plörer, D., Miller, J., Van Karsbergen, V., & Pfluger, R. (2024). Integrating Digital Twins with BIM for Enhanced Building Control Strategies: A Systematic Literature Review Focusing on Daylight and Artificial Lighting Systems. Buildings. https://doi.org/10.3390/buildings14030805.

CONFERENCE TOPIC

1.15. Sustainable Renovation and Energy Retrofits

FROM BIOGAS TO GRID: CO-ELECTROLYSIS AND METHANATION FOR HIGH-YIELD BIOMETHANE

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SUMMARY

Biogas represents a key component for the defossilisation of the Austrian gas market and, thanks to the existing gas infrastructure, offers excellent storage capabilities. Austria has a technically accessible biomethane potential of 8–12 TWh yr^{-1}, accounting for 10–15% of the current gas consumption. In Styria, the potential is estimated at 1.8–3.5 TWh yr^{-1}. Currently, biogas is injected into the grid following CO_2 separation (e.g., membrane processes); however, the separated CO_2 typically remains unused. By coupling SOEC co-electrolysis with methanation, this CO_2 can be converted into valuable products, substantially increasing CH_4 yield while minimizing the need for external H_2. The Renewable Gasfield in Gabersdorf with an existing methanisation plant provides ideal conditions as a living laboratory for validating this approach.

Keywords: biogas, biomethane, co-electrolysis, SOEC, methanation, defossilisation, gas grid, storage

INTRODUCTION

Austria consumed 74.4 TWh of natural gas in 2024, well below the five-year average of ~91 TWh (2018–2022); at the same time, the country has been in the third consecutive recession year since 2023 [1–4]. In contrast, the technically accessible biomethane potential amounts to 8–12 TWh yr^{-1}, complemented by 5–8 TWh yr^{-1} bio-SNG from woody biomass [5,6]. For Styria, recent assessments indicate 1.78–3.47 TWh yr^{-1} of renewable gases, of which 0.62–1.31 TWh yr^{-1} is biomethane [7]. With > 90 TWh of working gas capacity in Austria's porous reservoirs, the gas system offers unique seasonal storage for renewable gases [8].
Beginning Q4/2025, the Botres Global GmbH plant in Gabersdorf will inject purified biomethane into the Energienetze Steiermark grid—initially ~17 GWh yr^{-1} with potential for expansion. Raw biogas (typically ~52 vol% CH_4, ~46 vol% CO_2) must be upgraded to meet ÖVGW gas-quality standards (e.g. G B210) prior to injection [9]. CH_4 and CO_2 can be separated using various technologies, such as membrane processes, whereby the CO_2 typically remains unused and is released into the atmosphere. Methanation of this CO_2 would be technically possible but requires large amounts of green hydrogen, which - under current market conditions - does not make pure methanation economically viable.

Here, SOEC-based co-electrolysis combined with Sabatier methanation addresses this constraint: By co-electrolyzing CO_2 and H_2O, syngas ($CO + H_2$) is produced, which is then converted into CH_4 during the Sabatier methanation process (see Figure 1). This process integration avoids the external hydrogen requirement and uses the process heat from methanation to further increase efficiency.

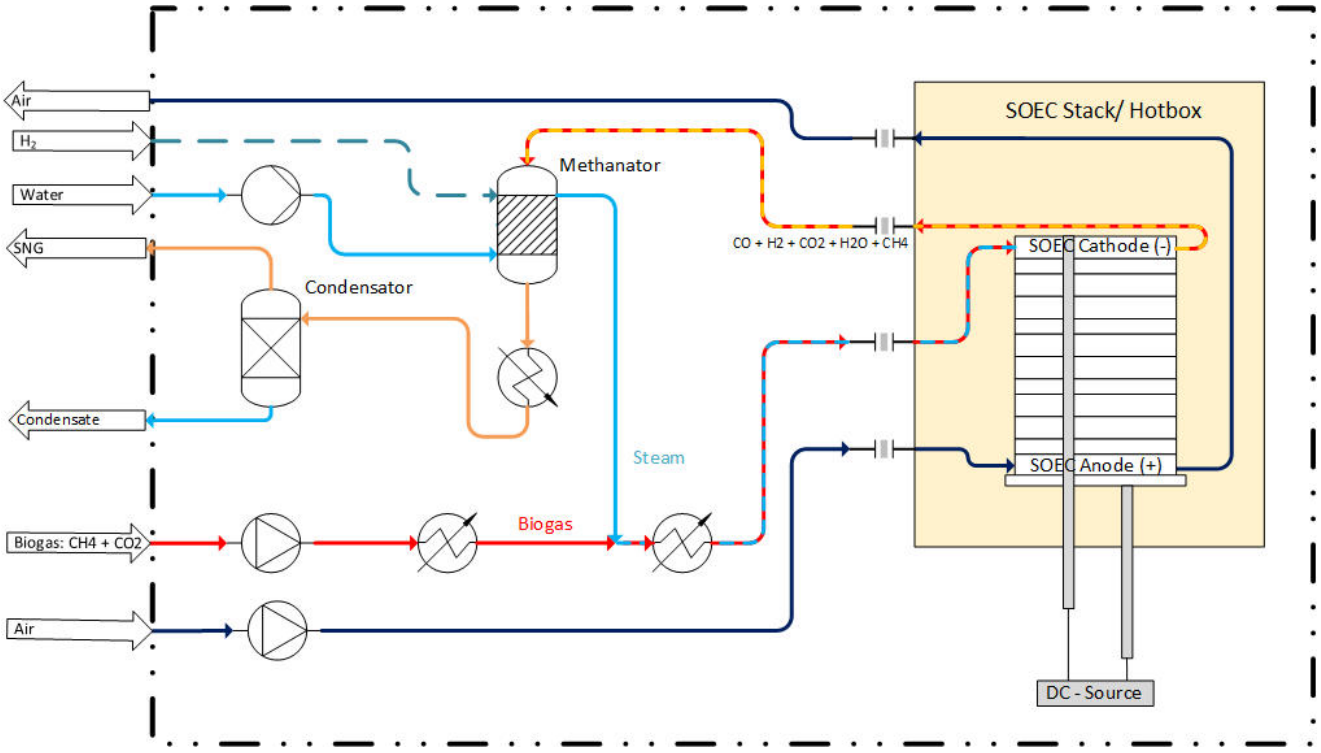


Fig. 1: Schematic process flow of the coupled process (SOEC and Methanation). Figure adapted from [15]

SOECs operate at high temperatures (650 – 900 °C) [10] and therefore achieve the highest efficiencies among current electrolysis technologies (65 – 85 $\%_{LHV}$) when thermal energy is supplied [11, 12]. The exothermic Sabatier methanation reaction operating at 200 – 400 °C enables effective thermal integration with SOECs, supporting highly efficient syngas production and substantially lowering production costs [13, 14].
Directly feeding CO_2/CH_4 mixtures to SOECs could eliminate the need for CO_2 separation of the biogas, a major barrier for large-scale deployment (see Figure 1) [15]. The role of CH_4 on SOECs, however, remains unclear. In typical Ni-based electrodes, CH_4 decomposes to CO and H_2, whereas trace H_2S can suppress this decomposition but introduces risks of sulphur poisoning and carbon deposition [16]. These interactions will be investigated in this work. The renewable gas field in Gabersdorf, with its existing infrastructure, offers optimal conditions to practically test this concept and further advance the defossilisation of the energy sector.

REFERENCES

[1] energie.gv.at, (2025), Gasmarktbericht 2024. BMK, Wien, Österreich
[2] E-Control, (2025), Branchenstatistik Erdgas 2024. Wien, Österreich
[3] Statistik Austria, (2025), Energieeinsatz nach Energieträgern – Jahresdaten 2024
[4] WIFO – Österreichisches Institut für Wirtschaftsforschung, (27.03.2025), Österreich steckt im dritten Rezessionsjahr. Prognose für 2025 und 2026. URL: https://www.wifo.ac.at/news/oesterreich-steckt-im-dritten-rezessionsjahr/ (abgerufen am 26.08.2025)
[5] Umweltbundesamt, (2023), Potenziale erneuerbarer Gase in Österreich. Wien, Österreich
[6] AGGM – Austrian Gas Grid Management, (2024), ONE100 – Bedarfsdeckung erneuerbare Gase. Wien, Österreich
[7] Lehrstuhl für Energieverbundtechnik (EVT), Montanuniversität Leoben, (2024), Grünes Gas Steiermark – Berechnung von Bandbreiten erschließbarer Potenziale an Biomethan und Synthetic Natural Gas (SNG) aus Reststoffen unter Einbindung eines Stakeholderprozesses, Graz/Leoben, Österreich
[8] E-Control, (2024), Gasmarktbericht Österreich – Speicher und Infrastruktur. Wien, Österreich

[9] ÖVGW – Österreichische Vereinigung für das Gas- und Wasserfach, (2021), Richtlinie G B210: Gasbeschaffenheit. Wien, Österreich
[10] Wolf, S., Vibhu, V., Tröster, E. et al. (2023), Steam Electrolysis vs. Co-Electrolysis: Mechanistic Studies of Long-Term Solid Oxide Electrolysis Cells, Energies 15, MDPI
[11] Hou, X., Jiang, Y., Wei, K. et al. (2024), Syngas Production from CO2 and H2O via Solid-Oxide Electrolyzer Cells: Fundamentals, Materials, Degradation, Operating Conditions, and Applications, Chemical Reviews 124, ACS Publications
[12] Yoon, K.J., Lee, S., Park, S.-Y. et al. (2025), Syngas Production from CO_2 and H_2O via Solid-Oxide Electrolyzer Cells: Fundamentals, Materials, Degradation, Operating Conditions, and Applications, Progress in Materials Science 154, Elsevier
[13] Chandraker, V., Paramasivan, G., Chandy, A.J. (2022), Computational investigations of enrichment effects for CO_2 methanation in Sabatier microchannel reactors, Chemical Engineering Research and Design 182, Elsevier
[14] Liu, Y., Sun, X., Chen, M., et al. (2023), Pathway toward cost-effective green hydrogen production by SOEC, Energy & Environmental Science 5, Royal Society of Chemistry
[15] Hansen, J.B., Fock, F., Lindboe, H.H. (2013), Biogas Upgrading: By Steam Electrolysis or Co-electrolysis of Biogas and Steam?, ECS Transactions 57(1), IOP Science
[16] Ebbesen, S.D., Hansen, J.B., Mogensen, M. (2013), Biogas Upgrading Using SOEC with a Ni-ScYSZ Electrode, ECS Transactions 57(1), IOP Science

CONFERENCE TOPIC

1.09. Hydrogen and Green Gas in Integrated Energy Systems

OPERATION AND OPTIMIZATION OPTIONS OF INTEGRATED SYSTEM OF REACTOR MODULES FOR SOLAR ENERGY CONVERSION INTO CHEMICALS

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SUMMARY

A solar-powered, integrated system of flow reactor modules for the production of chemicals from CO_2 and H_2O is presented that utilizes direct solar irradiation and solar derived electricity as energy inputs. The flow reactor modules are characterized as photo-electrochemical (PEC) (Holmes-Gentle et al. 2023), photo-thermal (PT) (Brust et al. 2024) and electrochemical (EC) (Ayyub et al. 2025) and are arranged in series to produce ethylene (C_2H_4) as target product as shown in Fig. 4. A demonstrator system including supporting optical and balance-of-plant components was assembled and tested under concentrated, simulated solar light at the German Aerospace Center (DLR). Mathematical models corresponding to the individual reactors were developed, subsequently combined into a system model and implemented in a process simulation software (Brust 2025) closely resembling the physical installation. Experimental results, improvement options and the potential for increases in solar-to-chemical conversion efficiency as predicted by the model are presented.

MOTIVATION

The European chemical industry is a major manufacturing sector, supplying essential materials to numerous downstream industries and representing a key economic factor. However, it remains heavily dependent on fossil fuels, emitting 155 million metric tons of CO_2 equivalent in 2021 (EU-27), about 5% of total net GHG emissions. This underscores the need for innovative technologies and processes to enable more sustainable chemical production.

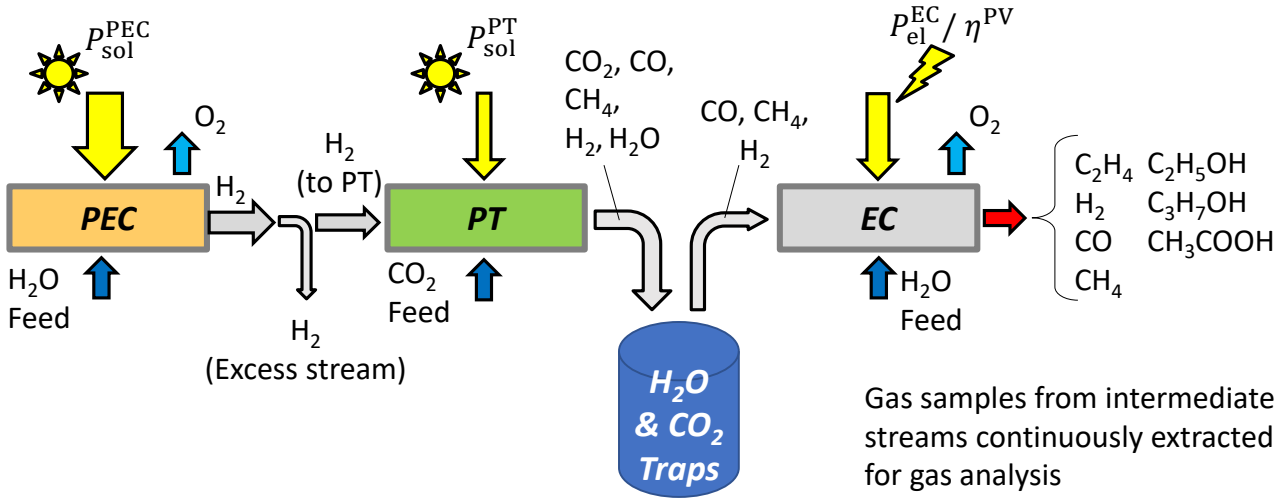


Fig. 4: Schematic flow diagram of the integrated system together with main process streams and species

SYSTEM OPERATION AND EXPERIMENTAL RESULTS

Over the course of the experimental testing the PEC, PT and EC reactor modules were operated for a total duration of 24.3, 21.8 and 13.7 hours, respectively, where differences in duration follow from the sequential start-up procedure. At the main operating point to which all following performance metrics refer to, a peak production rate of 55 mmol/h of C_2H_4 was obtained under mixed feed conditions (i.e. CH_4 and H_2 were present besides CO) in the EC module corresponding to a Faradaic Efficiency of C_2H_4 of 26.2%. The PT module produced CO at a rate of 340 mmol/h with a CO_2 conversion of 44% and selectivity towards CO of 57% based on CO_2 while H_2 was generated in the PEC module at a rate of 6.9 mol/h at a solar-to-hydrogen efficiency (STH) of 17% based on ΔH^{R} of which 3.7 mol/h were utilized in the PT module. Considering performance on the system level, solar-to-chemical efficiency can be defined based on the formation of the target product C_2H_4 in terms of ΔH^{R}, STC_1 in (eq. 1) or alternatively by including intermediate products H_2, CO and CH_4 in STC_2 in (eq. 2). For the main operating point, values of STC_1 of 0.64% and of STC_2 of 6.8% can be reported. The latter reaches slightly higher values (up to +1%), when C_{2+} species formed as by-products in the EC reactor module are factored in.

$$\mathrm{STC}_1\left(\Delta H^{\mathrm{R}}\right) = \frac{\dot{n}^{\mathrm{EC}}_{\mathrm{C_2H_4}} \Delta H^{\mathrm{R}}_{\mathrm{CO_2 \rightarrow C_2H_4}}}{P^{\mathrm{PEC}}_{\mathrm{sol}} + P^{\mathrm{PT}}_{\mathrm{sol}} + P^{\mathrm{EC}}_{\mathrm{el}} / \eta^{\mathrm{Si-PV}}} \qquad \text{(eq. 1)}$$

$$\mathrm{STC}_2\left(\Delta H^{\mathrm{R}}\right) = \frac{\dot{n}^{\mathrm{EC}}_{\mathrm{C_2H_4}} \Delta H^{\mathrm{R}}_{\mathrm{CO_2 \rightarrow C_2H_4}} + \dot{n}^{\mathrm{EC}}_{\mathrm{H_2}} \Delta H^{\mathrm{R}}_{\mathrm{WS}} + \dot{n}^{\mathrm{EC}}_{\mathrm{CO}} \Delta H^{\mathrm{R}}_{\mathrm{CO_2 \rightarrow CO}} + \dot{n}^{\mathrm{EC}}_{\mathrm{CH_4}} \Delta H^{\mathrm{R}}_{\mathrm{CO_2 \rightarrow CH_4}}}{P^{\mathrm{PEC}}_{\mathrm{sol}} + P^{\mathrm{PT}}_{\mathrm{sol}} + P^{\mathrm{EC}}_{\mathrm{el}} / \eta^{\mathrm{Si-PV}}} \qquad \text{(eq. 2)}$$

OPTIMIZATION OPTIONS

Diverse optimization options to increase the solar-to-chemical conversion efficiencies were identified. Reactants entered the PT reactor module with an unfavorably high H_2/CO_2 ratio of 2/1 due to operational challenges. PT reactor modeling shows that adjusting the H_2/CO_2 ratio towards 1/1 leads to a significant increase of the performance. Furthermore, modeling of the PT reactor suggests that design optimization is possible by varying the catalyst deposition depth yielding an increase in CO productivity over what was achieved experimentally. Applying the system model considering aforementioned improvement options and optimized reactor operating conditions with respect to maximum solar-to-chemical conversion efficiency, increases of STC_1 from 0.64% to 1.3% and of STC_2 from 6.8% to 8.7% are predicted. In addition, various technical advancements on reactor and system level could potentially further enhance the solar-to-chemical efficiencies.

REFERENCES

Ayyub, Mohd Monis; Fődi, Tamás; Endrődi, Balázs; Janáky, Csaba (2025): High performance CO reduction at electrolyzer stack level through system optimization. In: *Carbon Energy*, Artikel e674. DOI: 10.1002/cey2.674.

Brust, David (2025): Modeling and energetic assessment of reactor technologies for solar energy conversion into fuels and chemicals. Dissertation. RWTH Aachen University, Aachen.

Brust, David; Wullenkord, Michael; Gómez, Hermenegildo García; Albero, Josep; Sattler, Christian (2024): Experimental investigation of photo-thermal catalytic reactor for the reverse water gas shift reaction under concentrated irradiation. In: *Journal of Environmental Chemical Engineering* 12 (5), S. 113372. DOI: 10.1016/j.jece.2024.113372.

Holmes-Gentle, Isaac; Tembhurne, Saurabh; Suter, Clemens; Haussener, Sophia (2023): Kilowatt-scale solar hydrogen production system using a concentrated integrated photoelectrochemical device. In: *Nature Energy* 8 (6), S. 586–596. DOI: 10.1038/s41560-023-01247-2.

CONFERENCE TOPIC

This abstract refers to the Conference Topic 1.14. Solar-to-X Technologies for Fuels and Chemicals.

PROOF-OF-CONCEPT OF OSCILLATORY FLOW PHOTOREACTORS FOR SOLAR FUEL PRODUCTION IN REAL SUNLIGHT

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SUMMARY

Solar-to-X technologies such as photo(electro)chemical processes offer a direct route to converting sunlight into chemical bonds, but their practical application is limited by low efficiencies under real sunlight due to suboptimal reactor designs and constrained mass- and energy- as well as photon transfer. This study explores oscillatory flow as a process intensification strategy to enhance solar photoreactor performance. Optimized oscillatory-flow reactor designs were developed and tested for two target reactions: hydrogen (H_2) production from wastewater and CO_2 reduction to C_2+ products (e.g., ethanol), under both artificial and real sunlight. Proof-of-concept was achieved. As an example, in H_2 production oscillatory flow increased yields by a factor of 1.5–3 compared to static systems. Optimal conditions were identified at a Reynolds number of 249, with the setup demonstrating, for the first time, robust performance under real sunlight—providing key insights for translating photo(electro)chemical processes from laboratory studies to practical applications in real sunlight.

INTRODUCTION

The transition to a climate-neutral energy system requires sustainable pathways for producing carbon-neutral fuels and chemicals based on abundant molecules (CO_2, water, nitrogen) and waste. One promising approach is the conversion of solar energy into chemical bonds via solar-to-X technologies (Kargul etl. Al., 2023). While indirect solar routes mainly rely on water electrolysis powered by photovoltaic electricity, the scalability of green electricity supply is limited. This limitation underscores the need for additional technologies, directly using solar energy (photons), creating a balanced technology mix. Photochemical (PC) and photoelectrochemical (PEC) processes offer such a pathway for solar-to-fuel conversion, leveraging sunlight directly for chemical transformations, but face significant challenges, particularly regarding solar-to-fuel efficiency under real sunlight conditions. These limitations arise from the narrow spectral range of catalyst absorption, suboptimal reactor designs, and external environmental factors such as light and temperature fluctuations. While laboratory-scale studies for H_2 production have demonstrated efficiencies exceeding 6% for PC systems (Zhou et al., 2023) and approximately 19% for PEC systems (Song et al., 2022) under controlled conditions, real-world efficiencies remain considerably lower, typically 1–3% for PC systems and 3–4% for PEC systems (Tembhurne, Nandjou, & Haussener, 2019). The disparity is largely due to the non-ideal light distribution and energy/mass transfer in conventional reactor designs, as well as challenges in scaling these systems beyond small-scale laboratory setups. A critical barrier to practical implementation is the need for catalysts capable of efficiently utilizing the broader solar spectrum, particularly visible light, while maintaining long-term stability. Additionally, existing photoreactor configurations suffer from inefficient photon utilization, poor mass and energy transfer, omitted thermal management, and limited scalability, which together restrict performance in real-world applications.

OBJECTIVE AND METHODOLOGY

The objective of this study is to demonstrate oscillatory flow as a process intensification strategy for solar photoreactors applied for H_2 generation from wastewater and CO_2 reduction toward C_2+ products. Oscillatory flow improves light distribution, mass and energy transfer, and reaction kinetics, addressing key bottlenecks in

current photo(electro)chemical systems. This approach aims to bridge the gap between laboratory performance and real sunlight operation, paving the way for practical solar fuel production.
To achieve this, in this research optimized solar photoreactor designs were developed for the described processes and tested under artificial and real sunlight. A dedicated test stand with continuous measurement of key parameters (e.g., photocurrent, gas flow, irradiation) was engineered and constructed, integrating the different reactor and solar concentrator configurations. An example of the H_2 setup is shown in Figure 1. In the case of H_2 production, the experimental procedure assessed the influence of synthetic wastewater components (glucose, EDTA) as sacrificial agents at concentrations ranging from 10 to 1000 mg/L. A $BiVO_4$ photoanode was employed, and H_2 yield was continuously quantified via gas chromatography (GC) and correlated with measured sunlight intensity.

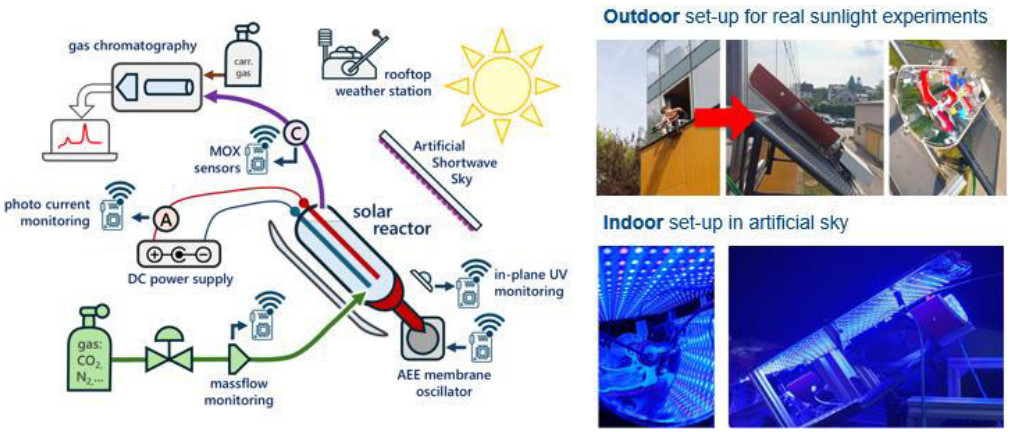


Fig. 1: Flexible test stand for indoor and outdoor photo(electro)chemical evaluation of solar photoreactors

For CO_2 reduction, experiments were conducted at varying CO_2 concentrations using catalysts optimized for real sunlight applications. Gas-phase products were monitored via gas chromatography (GC), while liquid-phase products were analyzed using proton nuclear magnetic resonance (^{1}H NMR) and GC–flame ionization detection (GC-FID), with results correlated to measured sunlight intensity. The effect of oscillatory flow on process efficiency was systematically evaluated by varying oscillatory Reynolds numbers (250–2600) through adjustments in amplitude (2.5–9 mm) and frequency (0.5–2 Hz). Indoor tests simulated real sunlight conditions, whereas outdoor experiments assessed the impact of natural irradiation variability on flow dynamics and light utilization.

RESULTS

Proof-of-concept was achieved for H_2 production and CO_2 reduction. In case of H_2 production, oscillatory flow significantly enhanced H_2 yield, achieving up to a factor 1.5–3 increase compared to non-oscillating systems. Optimal performance was observed at Reynolds number 249 (amplitude 10 mm and frequency 0,5 Hz). Under real sunlight, the system maintained stable performance despite fluctuating irradiation, demonstrating its robustness in changing conditions. Good correlation was observed between product yield (mmol/s) and irradiance (W/m²), underscoring the potential of oscillatory flow solar photoreactors for efficient, scalable solar fuel production.

REFERENCES

Kargul, J., Faber, C., et. Et. al . (2023), Unlocking the renewable energy future, Strategis Research and Innovation Agenda, Sunergy, https://sunergy-initiative.eu/wp-content/uploads/2022/12/SUNERGY_SRIA_November_2022.pdf

Song, H., Luo, S., Huang, H., Deng, B., & Ye, J., (2022), Solar-Driven Hydrogen Production: Recent Advances, Challenges, and Future Perspectives. ACS Energy Letters, 7(3), 1043–1065. https://doi.org/10.1021/acsenergylett.1c02591

Tembhurne, S., Nandjou, F., & Haussener, S., (2019), A Thermally Synergistic Photo-Electrochemical Hydrogen Generator Operating under Concentrated Solar Irradiation. Nature Energy, 4(5), 399–407. https://doi.org/10.1038/s41560-019-0373-7

Zhou, P., Navid, I. A., Ma, Y., Xiao, Y., Wang, P., Ye, Z., Zhou, B., Sun, K., & Mi, Z., (2023), Solar-to-Hydrogen Efficiency of More than 9% in Photocatalytic Water Splitting. Nature, 613(7942), 66–70. https://doi.org/10.1038/s41586-022-05399-1

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: 1.14. Solar-to-X Technologies for Fuels and Chemicals

CRYO-EM VISUALISATION OF PHOTOSYSTEM I NANOASSEMBLY ON SINGLE LAYER GRAPHENE VALIDATES ORIENTATION-DRIVEN IMPROVEMENT OF PHOTOCATALYTIC PERFORMANCE OF SOLAR-TO-FUEL SYSTEMS

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SUMMARY

We report the first cryo-EM visualisation and quantification of oriented Photosystem I (PSI) on single-layer graphene. Domain-specific covalent anchoring of PSI, with the reducing side of the biophotocatalyst towards graphene promotes three-fold higher anodic photocurrent generation compared to randomly physisorbed counterpart. This approach allows for the validation of the of photocatalytic nanoarchitecture aimed at significantly improved photochemical performance.
Keywords: Photosystem I; cryo-electron microscopy; biohybrid photoelectrodes; single-layer graphene; photocatalysis.

INTRODUCTION, RESULTS AND SIGNIFICANCE

Efficient solar energy conversion using the robust biomolecular photocatalyst, Photosystem I (PSI) remains a formidable challenge due to wasteful short-circuiting and charge recombination reactions caused by the random orientation of the PSI protein complexes on the electrode surface. Although multiple strategies have been explored to achieve some control over the directionality of electron flow in biosolar devices, a prerequisite for boosting the efficiency of solar conversion, a definitive demonstration and quantification of the biophotocatalyst orientation has thus far remained elusive.
Here, we report cryo-EM visualisation of PSI particles following domain-specific anchoring of this complex to the single layer graphene (SLG). By applying the rational design of the biomolecular interface we directly demonstrate the preferential orientation of the PSI complex with its reducing side towards the SLG. This approach is effective to enhance anodic photocurrent generation 3-fold compared to the nanosystem with randomly deposited PSI particles. This work provides a benchmark for the direct visualization of complex biomolecular electroactive nanoassemblies on advanced materials such as graphene monolayer. It also sets a new standard for the direct quantification of preferentially orientated photocatalytic biomolecules for the development of high efficiency solar-to-fuel devices.

Acknowledgements: This work was funded by the National Science Centre, Poland (Solar-Driven Chemistry 2 grant no. 2022/04/Y/ST4/00107). Part of this work was funded by the European Union (HORIZON CL5-2022-D3-03 SUNGATE grant, Grant Agreement no. 101122061).

CONFERENCE TOPIC

1.14. Solar-to-X Technologies for Fuels and Chemicals

INFLUENCE OF ALTERNATIVE DESIGN CONCEPTS ON THE TECHNOENVIRONMENTAL PERFORMANCE OF PHOTOCATALYTIC SYSTEMS

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SUMMARY

Light-driven processes such as photocatalysis represent a promising pathway for the sustainable production of fuels and chemicals, making it an active field of research. Projects such as DESIRED (Grant Agreement No. 101083355), focused on photocatalytic CO_2 valorisation, contribute to advancing this technology. However, the viability and sustainability of photocatalytic systems remain largely unexplored, requiring early assessments to guide development. This study presents a comparative life cycle assessment (LCA) of two design concepts for photocatalytic hydrogen production: liquid and gas phase reactors. The analysis is based on process simulations to build inventory data. Results show that the gas-phase system consistently performs better across all selected categories. Contribution analysis shows differences in the identification of environmental hotspots, linked to the specific technical aspects of each reactor design. The findings emphasise the importance of integrating environmental assessment into early-stage design to guide the development of photocatalytic systems.
Keywords: life cycle assessment, process simulation, photocatalysis.

INTRODUCTION

Solar energy stands out as a renewable resource offering a promising pathway for future fuel and chemical production due to its vast availability and energy potential. Within this context, light-driven processes such as photocatalysis are attracting increasing attention for their ability to harness sunlight directly to produce valuable compounds. Technologies such as those developed in the European project DESIRED, which target the photocatalytic conversion of CO_2 and H_2O into useful compounds, illustrate the potential of these systems. Photocatalytic approaches are also relevant to water splitting and nitrogen reduction, highlighting three major application areas: hydrocarbon production, hydrogen generation, and ammonia synthesis.
The sustainability performance of photocatalytic systems remains largely unexplored, even though early-stage environmental assessments are essential to identify design choices that can enhance their long-term viability. In particular, the influence of alternative reactor configurations on environmental performance has been scarcely addressed. This study contributes to filling this gap by comparing liquid and gas phase photocatalytic reactors for hydrogen production through LCA, with a focus on how design choices shape environmental sustainability outcomes.

MATERIALS AND METHODS

This work presents an exploratory case study designed to assess the environmental performance of alternative photocatalytic reactor configurations for hydrogen production. Two systems were analysed under comparable assumptions:

- Liquid-phase reactor system: inventory data were developed through conceptual process design and simulation based on an intrinsic kinetic model reported in the literature [1]. This photocatalytic system was scaled up to produce hydrogen under natural light irradiation.

- Gas-phase reactor system: inventory data were obtained from pilot-plant experiments carried out at IMDEA Energy, with operational results used to develop a kinetic model and scale up the system.

In both cases, the same photocatalyst (Pt/TiO_2) and ethanol as the sacrificial agent were considered. The systems were assumed to be located in Móstoles (Madrid, Spain), exposed to the same annual solar irradiation to ensure comparability. The photocatalytic process was simulated in Aspen Plus® for a production scale of 5 tonnes of hydrogen per day. A cradle-to-gate system boundary was defined, and the functional unit was set as 1 kg of pure hydrogen produced and compressed to 200 bar. Material and energy balances from the process simulation provided the basis for the foreground inventory data. Catalyst deactivation and regeneration cycles were included, and co-products were valorised within the system. Environmental impacts were assessed using the Environmental Footprint (EF) 3.1 method. Background processes were modelled with the ecoinvent 3.11 database, and LCA calculations were performed in SimaPro 10.2.

RESULTS AND DISCUSSION

The comparative LCA results indicate that the gas-phase system outperforms the liquid-phase configuration across all the selected environmental impact categories (Figure 1). Nevertheless, carbon footprint results above 30 kg CO_2 eq per kg of hydrogen in both cases, highly above the common threshold of 3 kg CO_2 eq per kg of hydrogen, suggest the need for further improvement. The contribution analysis reveals that platinum dominates the burdens in the gas- and liquid-phase reactor systems, while the gas-phase case is influenced by additional inputs such as steam and silica applied for carrier gas recovery and photoreactor body construction, respectively. These findings highlight that each design entails specific technical and environmental challenges. Furthermore, other technical aspects such as plant size and land availability remain critical for assessing the overall feasibility of photocatalytic hydrogen production.

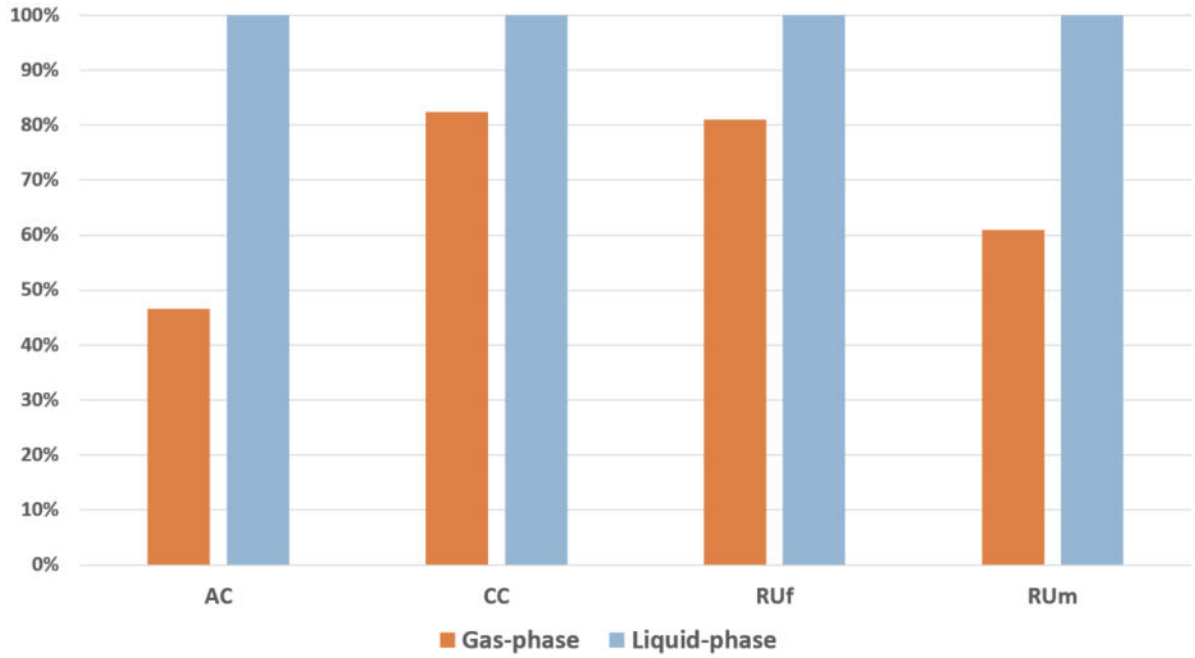


Fig. 1: Comparative analysis of potential environmental impacts for gas- and liquid-phase hydrogen production systems. AC: acidification; CC: climate change; RUf: use of fossil resources; RUm: use of minerals and metals.

CONCLUSIONS

This case study shows that the gas-phase photoreactor configuration outperforms the liquid-phase one in terms of environmental life-cycle performance. However, the carbon footprint of both systems remains far from the

European threshold of 3 kg CO_2 eq per kg of hydrogen for qualifying as green hydrogen. This underlines that substantial improvements are still required to bring photocatalytic hydrogen closer to environmental viability. The analysis highlights the need to jointly consider environmental performance, design aspects, and resource requirements in the early-stage development of photocatalytic systems. Further exploratory studies are required to address additional aspects and sustainability dimensions to support the sustainable scale-up of light-driven hydrogen production.

ACKNOWLEDGEMENT

This work was carried out within the framework of the DESIRED project (Grant Agreement No. 101083355), funded by the EU Horizon Research Programme. Authors gratefully acknowledge additional support from the SOLFuture project (PLEC2021-007906), funded by MCIN/AEI /10.13039/501100011033 and the European Union NextGenerationEU/PRTR.

REFERENCES

[1] M. R. Karimi Estahbanati, M. Feilizadeh, and M. C. Iliuta, 'An intrinsic kinetic model for liquid-phase photocatalytic hydrogen production', AIChE Journal, vol. 65, no. 11, e16724, Nov. 2019, doi: 10.1002/aic.16724.

CONFERENCE TOPICS

1.14. Solar-to-X Technologies for Fuels and Chemicals
2.04. Life Cycle Assessment

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MANAGING CARBON: IMPACTS OF CCUS FROM AN AUSTRIAN PERSPECTIVE

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SUMMARY

The future management of remaining CO_2 emissions in terms of carbon capture, utilization and storage (CCUS), is of growing importance for achieving set climate targets. Although the general necessity of CCUS is now largely undisputed, it is difficult to holistically compare the individual potentials of the various technologies and applications in terms of economic efficiency and environmental impact. This study addresses this issue by comparing the techno-economic performance and greenhouse gas (GHG) reduction potential of different CCUS pathways. Austria serves as a use case with regard to the relevant products and storage options. The results show that, from a microeconomic perspective and under the given and expected conditions, CCU is only partially competitive compared to current fossil fuel routes and CCS. From an ecological perspective, however, the use of CCU can contribute to significant GHG savings compared to CCS. In any case, the use of cost-effective and fully renewable energy sources is a basic prerequisite for the efficient integration of CCUS.

INTRODUCTION

As also addressed by the Austrian Carbon Management Strategy (BMF and BMK, 2024), recent analyses (Hochmeister *et al.*, 2024; Schützenhofer *et al.*, 2024) have shown that, depending on the defossilization path taken, Austria will still have 17-27 million tons of CO_2 emissions from the energy and industry sectors alone in the long term. Although a large part of this will be attributable to the use of biomass, 4-5.5 million tons of fossil- or geogenic-based emissions from hard-to-abate sources will remain, which will need to be addressed in order to achieve climate neutrality. This contrasts with the current carbon demand from the production of chemical raw materials and products equivalent to around 4 million tons of CO_2 (excluding gaseous and liquid fuels), which must be replaced by renewable production pathways if national value chains in this sector are to be maintained. In this context, different levels of CO_2 capture and utilization (CCU) and storage (CCS), respectively, are conceivable: While permanent storage or sequestration is essential for fossil and geogenic emissions, substitution by means of CCU is also an alternative to compensation through storage for the non-energy use of today's fossil raw materials.

This study analyzes these different CCUS pathways in terms of their economic performance and their potential for greenhouse gas (GHG) reduction. This included the assessment of costs related to the general binding of CO_2 as well as product generation, associated GHG emissions depending on energy supply mix, and corresponding GHG avoidance costs. The pathways were evaluated using varying parameters along the value chain, from the CO_2 source to capture, transport, and final utilization or storage in comparative scenarios to identify most relevant impact factors and related sensitivities.

RESULTS AND DISCUSSION

The techno-economic assessment of the various CCUS routes has shown that, in terms of pure CO_2 binding, without taking into account the possible binding duration, storage in the sense of CCS offers clear cost advantages

over utilization in hydrocarbons. This is mainly due to the high costs of (renewable) energy use in the form of electricity and hydrogen. In addition, it has been shown that the capture technology used and the type of CO_2 transport, if necessary, have only a minor impact on costs. When considering product manufacturing costs, however, individual CCU pathways can offer cost advantages over conventional production routes with CCS. This is particularly true when the compensation of emissions throughout the entire product life cycle, including end-of-life recycling, is taken into account (see Figure 8).

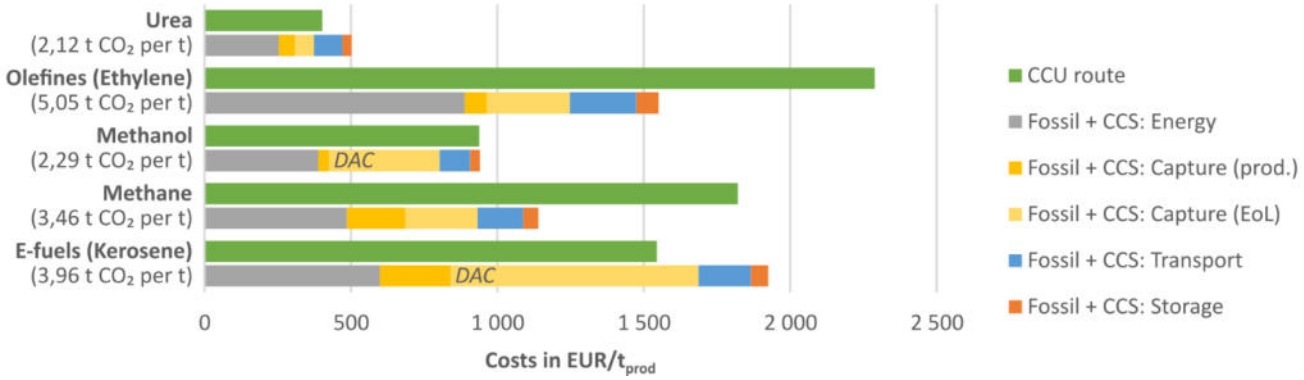


Figure 8: Marginal costs of CCU routes compared to conventional production with CCS of lifecycle emissions

From an ecological perspective, it became clear that an effective reduction in greenhouse gas emissions through CCU is only possible if the energy supply is covered entirely by renewable sources, including the upstream chain for producing the required hydrogen. Implementing CCU as a sustainable alternative to fossil production under currently given energy mixes, even if predominantly renewable, may even lead to an increase in total CO_2 emissions (see Figure 9). Consequently, this also affects the final GHG avoidance costs. Based on the elaborated economic and ecological impacts, GHG avoidance costs may differ by several orders of magnitude between the individual routes, while being the lowest for CO_2 sinks with longer binding periods.

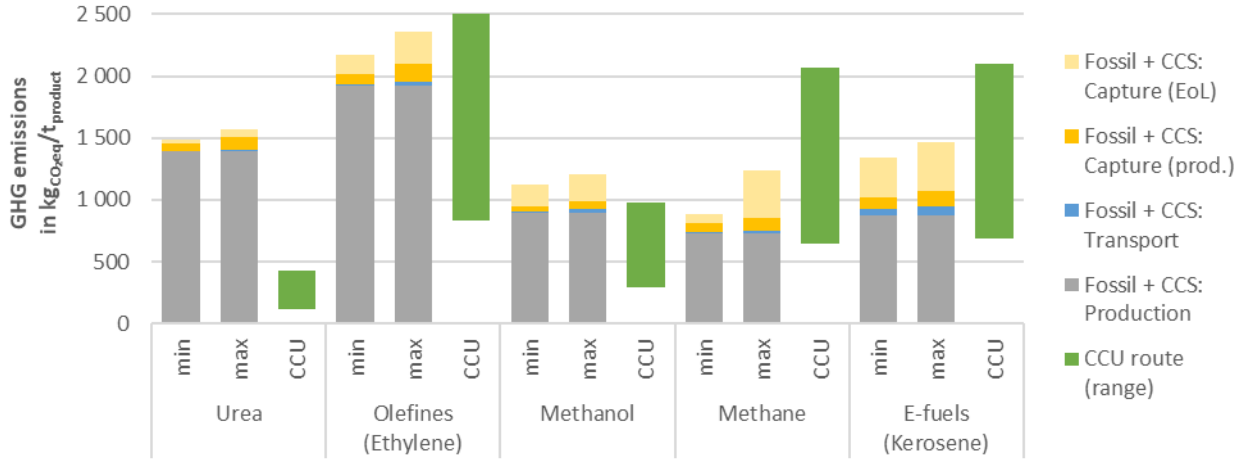


Figure 9: GHG emissions from CCU products compared to conventional production with CCS of lifecycle emissions

CONCLUSIONS

Based on the analyses carried out, it can be concluded that the sufficient availability of cost-effective and fully renewable energy sources is a basic prerequisite for the long-term effectiveness of CCUS in preventing climate change – from both an ecological and an economic perspective. Apart from this, reducing the energy required for CO_2 capture and transport, regardless of the technologies used, is a relevant factor for the future effects of CCUS, which equally affects both new CCU routes and conventional fossil fuel production using CCS. Furthermore, the analyses have shown that CCU can offer significant individual advantages over CCS-based solutions for climate-

neutral products, even if different paths may be prioritized when considered individually, depending on the focus on economic efficiency or GHG savings.

ACKNOWLEDGEMENT

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REFERENCES

BMF and BMK (2024) 'Österreichische Carbon Management Strategie (CMS)'. Edited by Bundesministerium für Finanzen (BMF) and Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität,Innovation und Technologie (BMK). Available at: https://www.bundeskanzleramt.gv.at/dam/jcr:5f4cb93a-802d-4230-b61c-e1a83460d142/103a_1_mrv.pdf (Accessed: 9 September 2025).

Hochmeister, S. *et al.* (2024) 'A methodology for the determination of future Carbon Management Strategies: A case study of Austria', *International Journal of Sustainable Energy Planning and Management*, 41, pp. 108–124. Available at: https://doi.org/10.54337/ijsepm.8280.

Schützenhofer, C. *et al.* (2024) *Machbarkeitsstudie über ein CO2-Sammel- und Transportnetz in Österreich*. Studie. i.A.v. Bundesministeriums für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie (BMK). Available at: https://www.bmluk.gv.at/dam/jcr:94c35c7f-222d-4d9c-8128-c490075dd0c0/CO2Netz_Bericht_241007%20(1).pdf (Accessed: 12 September 2025).

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
1.11. Net-zero/negative Emissions in the Industry including CCUS

CLOSING THE CARBON LOOP - AMINE SCRUBBING AND CATALYTIC METHANATION AT AN INTEGRATED STEEL-MILL

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SUMMARY

The Project ZEUS (Zero Emissions troUgh Sectorcoupling) enhances the utilisation of green hydrogen (H_2) for wide range applications by upgrading a running 6 MW PEM electrolyser through purification and compression. Additionally, ZEUS demonstrates the use of CO2 to produce synthetic methane in the steel industry. These pilot plants contribute to closing the carbon loop, thus reduce CO2 emissions and accelerate the transfer of these technologies into industry. As part of the project, an amine scrubber is operated in an integrated steel mill to capture real off-gases. The capacity of the pilot plant is up to 800kg of CO_2 per day using different solvents, including monoethanolamine (MEA) and activated methyldiethanolamine (aMDEA). A comparison of the solvents shows, that aMDEA has a specific regeneration energy of 3.3 GJ/t_{CO2} whereas the energy required for MEA is 3.7 GJ/t_{CO2}. The captured CO_2 as well as the green H_2 are utilised for methane synthesis with up to 99.9% conversion efficiency.

INTRODUCTION

Within the project ZEUS different CO_2 reduction pathways are being investigated, including green H_2 production for direct carbon avoidance as well as carbon capture of unavoidable CO_2 emissions. To evaluate potential carbon capture strategies, an amine scrubber is employed within an integrated steel mill. While carbon capture technologies reduce emissions at its source, transforming the captured CO_2 into valuable products is crucial to close the carbon loop. Therefore, ZEUS is targeting catalytic methanation, focussing on the development of novel catalysts and reactor design with emphasis on operating the pilot plant under real industrial conditions. These pilot plants demonstrate process potential and provide a basis for scalability. The goal of ZEUS is the development and cross-sectoral demonstration of a climate-neutral process chain - from the production and processing of green hydrogen under fluctuating process conditions to the separation of CO_2 from industrial exhaust gases and the conversion into valuable products. This abstract specifically highlights the process of amine scrubbing for CO_2 capture and the catalytic methanation process.

RESULTS

An amine scrubber pilot plant with a capacity of 800 kg/day is used to capture CO_2 from the industrial off-gas of an integrated steel mill's power plant. Different solvents are tested to minimize the regeneration energy required as well as to minimize the solvent degradation. In the first two years of the project, two different solvents were compared, monoethanolamine (MEA) and activated methyldethanolamine (aMDEA). Preliminary results from the solvent comparison show that process parameters, such as the liquid to gas ratio, must be significantly altered to achieve feasible points using aMDEA. To reach a separation efficiency of 90%, the liquid-to-gas ratio, which is defined by the volumetric flow of the liquid solvent and the volumetric gas flow of the off-gas, needs to be about twice as high compared to MEA. A comparison of the specific regeneration energy of both solvents reveals that aMDEA requires significantly less energy than MEA. **Figure 1** shows that the regeneration energy for aMDEA is around 3.3 GJ/t_{CO2} while the energy needed for MEA is 3.7 GJ/t_{CO2}.

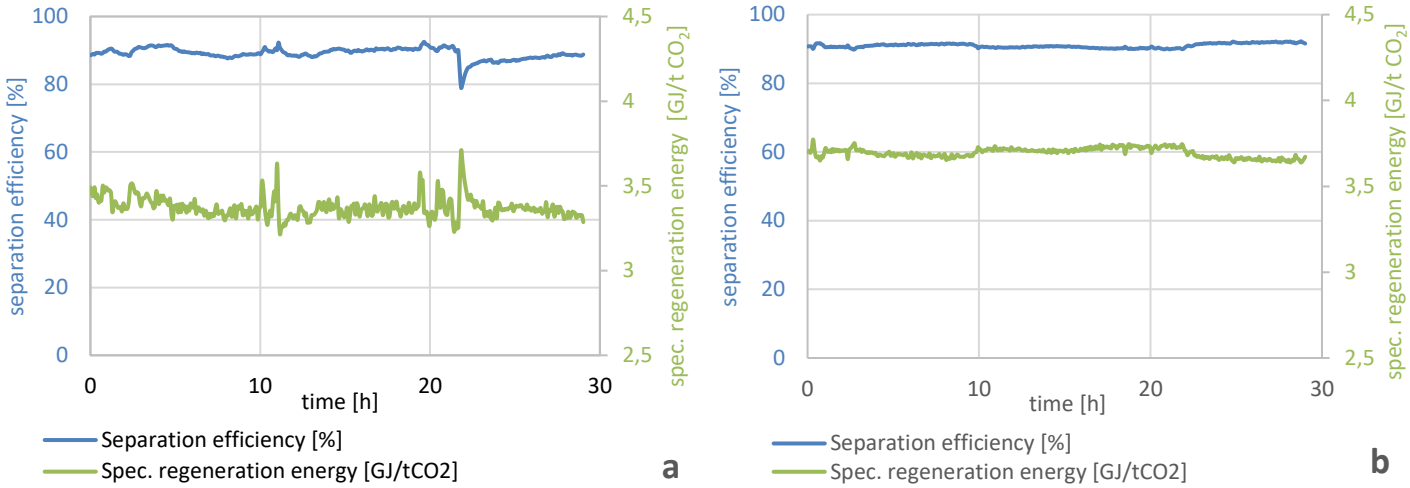


Figure 10. Comparison of specific regeneration energy aMDEA (a), MEA (b) at 90% seperation efficiency.

An existing pilot plant for catalytic methanation is operated under real industrial conditions using captured CO_2 from the amine scrubber and H_2 from the 6 MW PEM electrolyser. Around 10 Nm^3/h of synthetic natural gas is produced, which is fed directly into the power plant gas injection system, thereby closing the internal carbon cycle. Various process parameters, including GHSV (gas hourly space velocity), temperature, pressure, H_2-surplus and catalyst type were assessed to determine the impact on the methanation reaction. In addition, the durability of the catalyst was evaluated, under steady operation and dynamic feed gas flow rate. **Figure 2** illustrates the influence of temperature and pressure on the conversion rate of CO_2 to methane (CH_4).

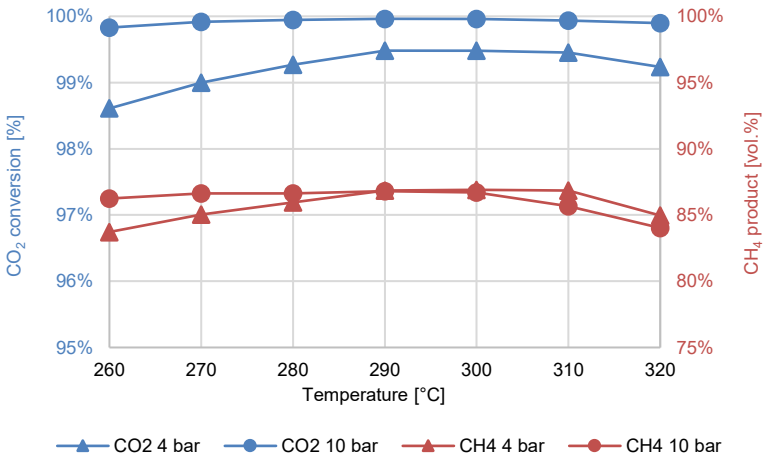


Figure 11. CO_2 conversion and CH_4 production rate over temperature at 4 and 10 bar.

CONCLUSION

In conclusion, the ZEUS project aims to speed up the transfer of climate-friendly technologies to industry by testing real off-gas streams in pilot scale. This includes the production of green hydrogen, carbon capture using amine scrubbing as well as catalytical methanation for utilisation, which have the potential for large scale application.

CONFERENCE TOPIC

Net-zero/negative Emissions in the Industry including CCUS

Gefördert durch
Bundesministerium Innovation, Mobilität und Infrastruktur

FOOD-GRADE CO_2 RECOVERY VIA TEMPERATURE SWING ADSORPTION: IPSE PROCESS SIMULATION FOR NET-ZERO BIOMASS INDUSTRIES

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SUMMARY

Food-Grade CO_2 Recovery via Temperature Swing Adsorption (TSA) is studied as a net-zero solution for biomass industries. Replacing Austria's 381 kt/year fossil CO_2 demand in food, beverage, and greenhouse applications could cut 0.52 % of national emissions. TSA delivers ≥99 % purity without cryogenic liquefaction, unlike amine scrubbing (AS). With <1500 kWh/tCO_2 energy use, TSA lowers costs and ensures direct-use readiness. Using solid amine sorbents, it avoids solvent degradation and reduces regeneration energy. Simulations with Toth- and BET-isotherms support industrial-scale TSA designs, showing clear energy savings versus AS. Pilot-scale validation will guide industrial deployment in biomass–food sector integration.

Key words: Temperature Swing Adsorption, Food-grade CO2, Biogenic CO2, Solid amine sorbents, Net-zero emissions, IPSE Pro Simulation

INTRODUCTION

This study addresses net-zero emissions in biomass-based industries through process simulation of food-grade CO_2 capture through Temperature Swing Adsorption (TSA). The research targets direct CO_2 utilization for industrial applications (e.g., beverage carbonation, food packaging, greenhouse cultivation). These applications require 381 kt/year fossil CO_2 in Austria as raw material and additive (not for energy provision), corresponding to -0.52 % national emissions reduction potential through substitution with biogenic CO_2 from biomass processing facilities.

Beside improved energy efficiency and reduced capital costs, shown in Fig. 1, the TSA's critical advantage over conventional amine scrubbing (AS) lies in eliminating energy-intensive liquefaction requirements to reach required product purity. While amine systems require additional cryogenic purification (>30 % energy penalty) after CO_2 separation to reach food-grade specifications (≥99 % purity), TSA delivers consistent high-purity CO_2 suitable for immediate industrial use without downstream processing. This changes the traditional capture-purify-utilize chain, while fundamentally optimizing energy profiles from capture efficiency regardless of purification costs to minimizing total system energy consumption (<1500 kWh/tCO_2) including utilization preparation.

TSA versus liquid AS

1. Improved Energy Efficiency
   a. Lower heat capacity of CO_2 carrier
   b. No evaporation of water in regenerator
   c. Increased CO_2 transport capacity
2. Reduced Capital Costs
   a. Less stages → smaller contactors
   b. Less corrosion → cheaper materials
   c. Less pollutants → no post-

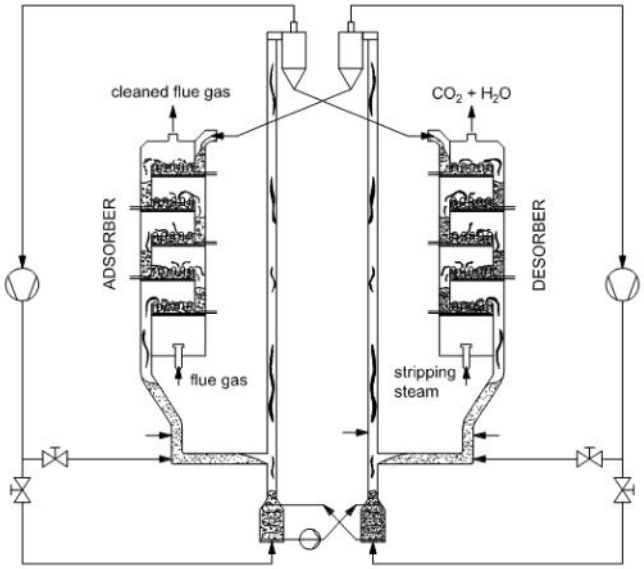


FIG. 1: PROCESS SCHEME AND ADVANTAGES OF THE TSA PROCESS

In contrast to AS systems, TSA utilizes solid sorbent materials where amine molecules are covalently immobilized onto solid supports such as polymeric resins. This immobilization approach differs from liquid AS by eliminating solvent degradation issues and reducing energy consumption associated with solvent circulation and regeneration. The solid amine sorbents in TSA systems achieve selective CO_2 adsorption through chemical interaction between CO_2 molecules and immobilized amine groups, forming stable carbamate species that can be readily desorbed through temperature increase.

Our simulation methodology addresses three critical gaps for direct-use of the TSA implementation for a net-zero industry:

1. Modelling of specific isotherms regarding adsorption of CO_2 and H_2O, including Toth-isotherms for CO_2, a co-adsorption factor and BET-Isotherms for H_2O.
2. Modelling enhanced TSA designs achieving industrial-scale operation while eliminating liquefaction steps that amine systems require for purity assurance.
3. Quantifying TSA's direct-use benefits versus conventional amine scrubbing across three industrial stakeholder scenarios, demonstrating energy savings through simplified carbon value chains.

Simulation results will be validated through pilot-scale testing in an already existing TSA-Unit to verify process performance and optimize industrial implementation strategies. This work establishes a framework for direct-use CCUS deployment specifically targeting the food industry as an initial implementation case. The biomass processing sector presents advantages, where biomass boilers and CO_2 utilization facilities are co-located, enabling immediate on-site utilization of captured biogenic CO_2 without transportation costs, transforming industrial CO_2 from processed commodity to immediately usable carbon resource while advancing net-zero decarbonization through simplified utilization pathways, particularly suitable for food processing facilities requiring both thermal energy from biomass combustion and high-purity CO_2 for packaging and preservation applications.

CONFERENCE TOPIC

Net-zero/negative Emissions in the Industry including CCUS

„Dieses Projekt wird aus Mitteln des Klima- und Energiefonds und des Bundesministeriums für Innovation, Mobilität und Infrastruktur gefördert und im Rahmen des Energieforschungsprogramms 2025 durchgeführt.“

ELECTRIFICATION POTENTIAL FOR INDUSTRIAL DECARBONISATION IN QUEBEC

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SUMMARY

This study evaluates the potential for electrification in thirteen industrial sectors in Quebec: aluminum, pulp and paper, steel, refineries, iron ore mining, cement, alumina, gold and silver mining, chemicals, agrifood, wood products, and lime. Two long-term electrification scenarios are evaluated: a techno-optimistic scenario assuming complete theoretical electrification regardless of technology maturity, and a high-technology readiness Level scenario (high-TRL), limited to technologies available on the market or close to commercialisation. The techno-optimistic scenario reduces fossil fuel use by 71%, increases electricity demand by 52%, and reduces greenhouse gas (GHG) emissions by 46%, at an additional annual energy cost of approximately C$640 million. In Quebec, where the electricity grid is clean, electrification can significantly reduce industrial GHG emissions, but not entirely and requires a significant amount of electricity and considerable investment in electrification technologies, and power production and transmission.

INTRODUCTION

Industrial decarbonisation is a key pathway for achieving net-zero CO_2 emissions by 2050. Replacing fossil fuels with Quebec's low-carbon electricity can take various forms, but industrial process heating represents a large share of industrial energy demand. The focus is on high-carbon-intensity activities where proven, commercially viable, low-carbon alternatives are lacking in the short term.

With Quebec's electricity being 98% from renewable sources, electrification is a strategic priority for decarbonisation across all economic sectors. Electrically powered systems generally outperform fossil fuel systems, meaning electrification can both curb future energy demand growth and significantly cut GHG emissions.

This study proposes and evaluates electrification projects, by sector and equipment, to estimate additional required electricity consumption and potential CO_2 reductions. Due to uncertainty over investment costs for emerging technologies, full techno-economic assessments are excluded, except for energy cost increases.

ASSESSING ELECTRIFICATION POTENTIAL IN INDUSTRY: PROCESS TEMPERATURE AND TECHNOLOGY APPLICABILITY

Assessing the potential for industrial electrification requires identifying fossil fuel consumption by process, determining viable electrotechnology substitutes, and estimating the resulting energy shift from fossil fuels to electricity. Electrification is limited when fossil fuels are used as non-energy inputs or when combustion is intrinsic to the process, although emerging solutions such as molten oxide electrolysis, electrolytic hydrogen, and inert-anode aluminum production are promising. For process heating, technology applicability depends strongly on operating temperature: below 200 °C, most methods (resistance, induction, radiant heating, electric boilers, heat pumps) are suitable; between 200 - 700 °C, resistance heating remains a simple and effective choice; above 700 °C, fewer high-cost, process-specific technologies are available, including electric furnaces and plasma torches. Hydrogen combustion can also provide very high temperatures as an indirect electrification pathway. Mapping industrial process temperatures provides a crucial first step in determining the suitability of electrification options.

RESULTS

Two scenarios for industrial electrification are presented (see Fig. 12):

- The techno-optimistic scenario includes emerging and future technologies, resulting in a larger increase in electricity demand (39 TWh) but also deeper cuts in fossil fuel use (184 PJ) and GHG emissions (12.7 Mt CO_2), requiring approximately C$640 million for additional energy costs only.
- The high TRL scenario relies only on currently or soon-to-be available technologies, resulting in a smaller increase in electricity consumption (25 TWh) and more modest fossil fuel (105 PJ) and emissions (6.1 Mt CO_2) reductions, requiring approximately C$540 million for additional energy costs only.

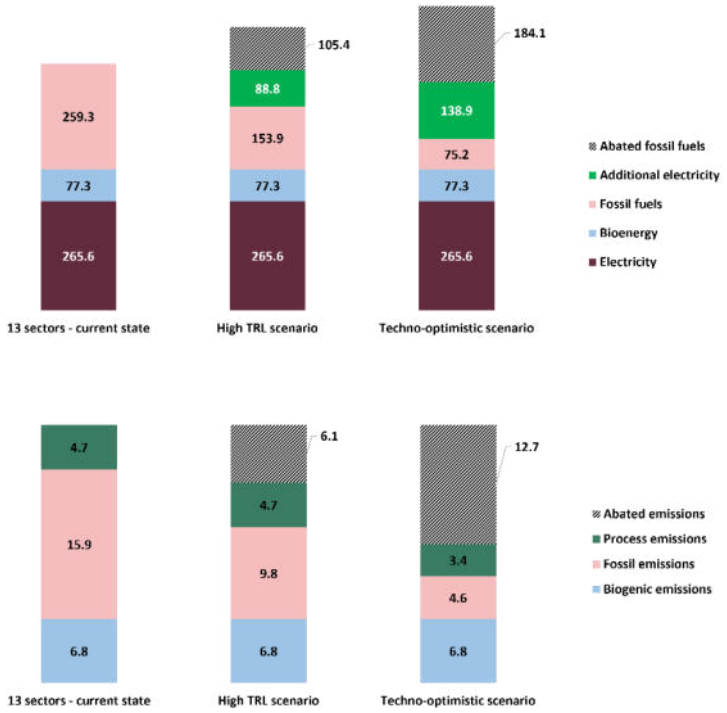


FIG. 12: ENERGY CONSUMPTION (PETAJOULE) (TOP); GHG EMISSIONS (MILLION TONNES CO_2) (BOTTOM)

REFERENCES

Fraunhofer ISI (2024): Direct electrification of industrial process heat. An assessment of technologies, potentials and future prospects for the EU. Study on behalf of Agora Industry.

CONFERENCE TOPIC

Net-zero/negative Emissions in the Industry including CCUS

CCU PATHWAYS IN AUSTRIA: A LIFE CYCLE-BASED ASSESSMENT OF CLIMATE TARGET COMPATIBILITY AND MITIGATION POTENTIALS

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SUMMARY

The integration of carbon dioxide into industrial production to support Austria's 2030 and 2040 climate targets requires timely technological maturity and measurable greenhouse gas reductions compared to conventional pathways. This study evaluates nine carbon capture and utilization (CCU) technologies for their applicability in Austria's industrial and energy sectors. Three of the investigated technologies are classified as compatible with Austria's 2030 targets: direct hydrogenation to methanol, high gravity carbonation, and carbonation of steel slag blocks. In 2040, only the mineralization pathways remain compatible, provided that biogenic CO_2 is utilized. A substitution-based approach is applied to quantify mitigation potentials, resulting in savings of up to 43 $MtCO_2e$ in 2030 and 23 $MtCO_2e$ in 2040. Overall, each of the investigated technologies demonstrates greenhouse gas (GHG) mitigation compared to their conventional counterparts and may serve as transitional solution on the journey to climate neutrality.
Keywords: CCU, LCA, climate targets, CO_2 emissions, hard-to-abate, greenhouse gas mitigation

INTRODUCTION

The European Climate Law obliges member states to reduce net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels and to achieve climate neutrality by 2050. In response, National Energy and Climate Plans (NECPs) outline the respective strategies to meet these targets. Austria's NECP prioritizes emission reduction and energy efficiency measures and includes the ambitious goal of reaching net-zero emissions by 2040. However, a progressive calculation scenario predicts around 14.8 Mt of so-called 'hard-to-abate' emissions (Fig. 1 left), persisting mainly due to technological and process-related constraints in industrial and energy sectors. For such cases, the deployment of carbon capture, utilization, and storage (CCUS) technologies is proposed.

CONCEIVABLE CCU TECHNOLOGIES

In this work, nine conceivable carbon utilization technologies for deployment within Austria's industrial and energy sectors are investigated: (1) carbonation of steel slag blocks, (2) high gravity steel slag carbonation, (3) direct hydrogenation of CO_2 to CH_4, (4) Direct hydrogenation of CO_2 to Methanol, (5) Fisher-Tropsch synthesis with syngas obtained via reverse water-gas shift reaction, (6) CO_2 hydrogenation in methanol to dimethoxymethane (DMM), (7) electrochemical CO_2 reduction to ethylene, (8) CO_2 bio-fermentation to acetone, and (9) CO_2-based polyol production. Life cycle assessment (LCA) studies act as basis for this work, for which the data has been harmonized according to clearly defined rules and specified boundary conditions. The harmonization enables a consistent evaluation of the technologies in terms of Austria's climate target compatibility and estimations of GHG reduction potential through substitution of conventional products. According to the predefined thresholds in the NECP, technologies are categorized as 2030-compatible if their emissions are below 55% of those from conventional counterparts, and as 2040-compatible if they achieve net-

zero emissions or carbon dioxide removal. Consequently, and under consideration of technological readiness, three technologies can meet Austria's 2030 climate target: carbonation of steel slag blocks, high gravity steel slag carbonation, and direct hydrogenation to methanol. For 2040, only the utilization of biogenic CO_2 through mineralization routes remains compatible, due to benefits of long-term storage and reintegration into the natural carbon cycle. The re-emission of fossil or geogenic CO_2 after CCU causes additional atmospheric GHG accumulation, making the strict 2040 climate targets unachievable. However, the substitution approach demonstrates that each technologiy may act as a GHG mitigation measure if a conventional product is replaced. From this perspective, CCU represents valuable transitional solutions on the path to climate neutrality. The proposed sector-specific CCU pathways yield GHG savings of 43 million tonnes CO_2e in 2030 and 23 million tonnes CO_2e in 2040. These optimistic estimates do not account for various limiting factors such as energy demand, feedstock availability, hydrogen supply, and market constraints. Therefore, the results should be regarded as theoretical. The assessment of the real mitigation potentials requires further case-specific evaluations.

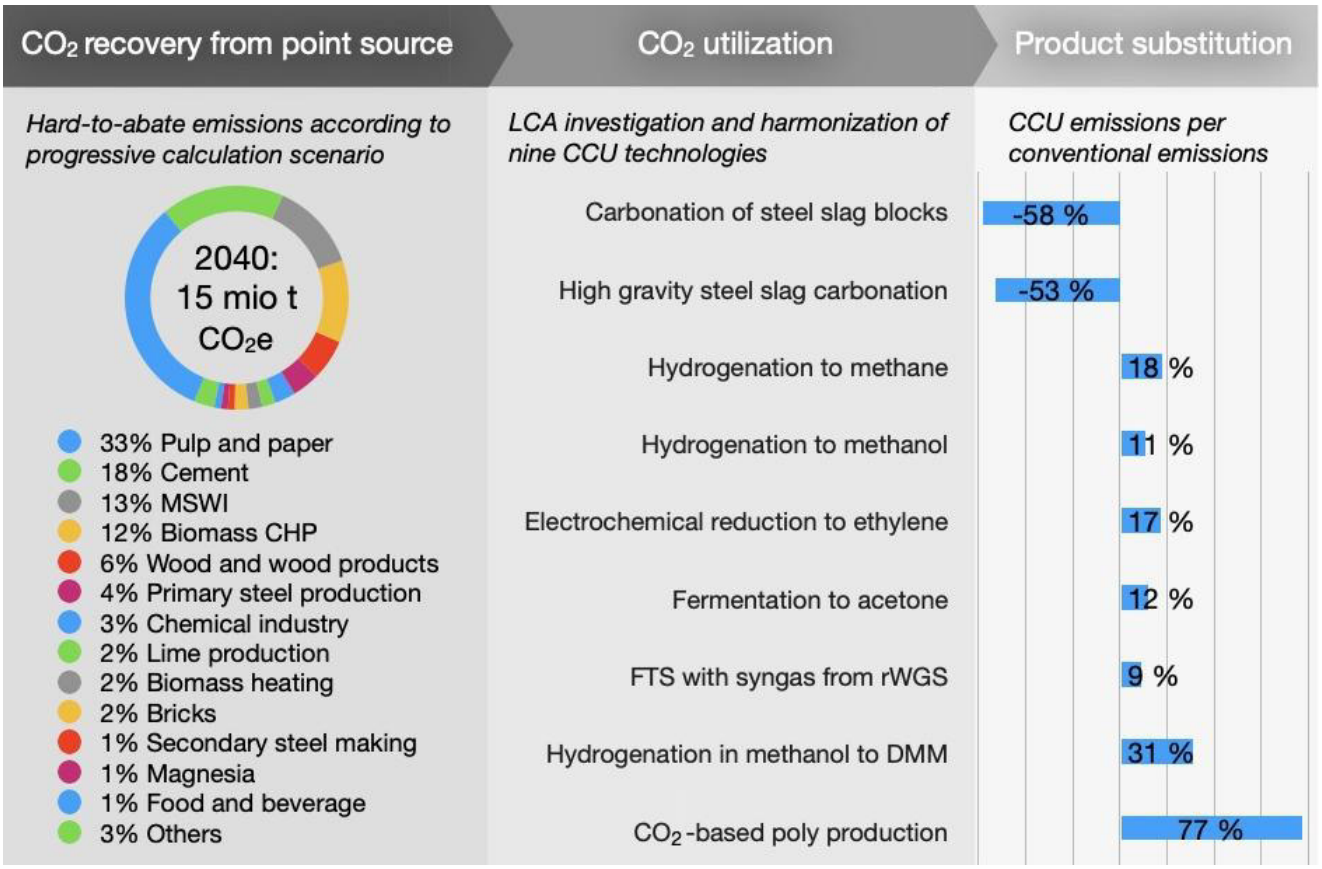


Fig. 1: (left) Share of hard-to-abate CO_2 emissions per sector in 2024, and (right) CCU pathways with their potential for CO_2 emission reduction compared to conventional production

REFERENCES

E. C. D.-G. for Communication, (2020), The European climate law. Publications Office doi: 10.2775/790913.

U. E. M. I. und T. Bundesministerium für Klimaschutz, (2024), Integrierter nationaler Energie- und Klimaplan für Österreich.

Hochmeister, S., et al., (2024), A Methodology for the Determination of Future Carbon Management Strategies: A case study of Austria. International Journal of Sustainable Energy Planning and Management, vol. 41, pp. 108–124, doi: 10.54337/ijsepm.8280.

CONFERENCE TOPIC

1.11. Net-zero/negative Emissions in the Industry including CCUS

GRID-FORMING CONTROLLERS IN THE DISTRIBUTION NETWORK LANDSCAPE

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SUMMARY

The rapid expansion of renewable capacity is reshaping the power system landscape by introducing new actors into play, such as prosumers and energy communities, that would play a key role in the stability of the network under the distribution system landscape. This acceleration on the deployment of PV, wind and battery system is leading to an extended use of an advance control strategies that mitigate the loss inertia, flexibility and support towards the grid, so-called grid-forming (GFM) control. The decline of conventional synchronous generators has reduced native system inertia, leaving networks, transmission and distribution, more vulnerable to instability. Thus, massively reducing the time of actuation necessary to avoid escalated fault scenarios. In this regard, GFM technology offers a potential solution for synthetic inertia emulation and dynamic support for both voltage and frequency deviations, making it a key tool for enhancing stability in renewable-dominated distribution networks of the future. However, large-scale deployment increases the risk of oscillations and uncontrolled interactions due to voltage regulators and synchronization mechanisms or islanding procedures. Addressing these challenges is crucial to ensure the safe, reliable and coordinated integration of distributed GFM resources in future power systems.

INTRODUCTION

The rapid growth of photovoltaic (PV) installations estimated about ~320 GW by 2025 and projected to reach a capacity close to the 600 GW by 2030 [1], has transformed the electrical landscape introducing new market participants into the scenario. These include households that both produce and consume electricity from the grid, with the capacity to provide grid-support and flexibility services, thereby strengthening the operational reliability of the network. In Europe, energy communities and microgrids have significantly advanced in efficiency and use of energy, largely due to the integration of power electronic converters and the smart deployment of battery energy storage systems. However, the overall poor management of renewable generation systems poses risks to the electrical network stability, which has been already seen in some failures in Australia and the U.S, and even in more sever cases, in the national blackout in Spain. In addition to this, the growing adoption of electric transportation increases the stress on the network. The integration of mobile loads that can create daily demand fluctuations depending on charging patterns is one of the key challenges. Some mitigation as well established by the integration of battery storage capacity, that in some cases has exceeded the GW installation in one year. Those systems can absorb excess energy during peak demand, allowing for some alleviation of variability in the power responses. However, with this massive integration and the removal of synchronous generators the power system has experienced a continuous decline in inertia and grid strength. While this remains a pressing challenge for the power system, the integration of advanced power electronic control algorithms has alleviated the issue through the adoption of GFM technologies [2], systems that can emulate the dynamic behaviour of synchronous generators. In this regard, battery energy systems are particularly suited for the GFM emulation. Their stable DC link can enable bidirectional responses to both frequency and voltage deviations, making them a key asset for enhancing the network stability and resilience. Many concerns are arising on the interoperability of systems specially with the integration of GFM on PV assets, since operational discrepancies across devices may amplify interactions, leading to uncontrolled oscillations and possibly to unintended power exchanges across the distribution network.

GRID-FORMING CONTROL

Conventional synchronous power plants inherently provide grid stability through their rotating masses, which supply inertia, maintain voltage, and establish system frequency as part of the electromechanical dynamics of the machine. Their control is relatively slow but naturally coordinated, as frequency and voltage emerge from the physical coupling of generators. In contrast, converters equipped with grid-forming controllers emulate these

stabilizing properties through fast control algorithms rather than mechanical inertia. They can establish voltage and frequency in weak or inverter-dominated grids, respond much faster to disturbances, and be flexibly tuned for different operating conditions. However, unlike synchronous machines, GFMs require careful parameter design, coordination, and protection schemes to ensure stable interaction with other resources. This makes them more versatile and flexible, but also more complex to deploy and integrate at large scale. For instance, adverse interactions between grid-forming units have been observed in the field, which are still not very well understood. Moreover, their characteristics in terms of overcurrent are much more limited than in conventional units. While the implementation of grid-forming control for type D systems directly connected to the 110 kV grid may be more straightforward, this was not the focus of the original investigations. Instead, the studies concentrated on the integration of grid-forming control into local low-voltage distribution networks. The findings indicate that grid-forming technology offers promising capabilities for stabilizing converter-dominated grids. However, its deployment at the distribution level introduces several challenges. Key concerns include personnel safety due to unintended islanding and the adaptation of protection schemes. The additional short-circuit power introduced by grid-forming inverters may not always be beneficial and the technology can lead to unintended islanding and controller oscillations, potentially compromising system stability and operational reliability. From the perspective of distribution system operators (DSOs), grid-forming control can help mitigate voltage issues in weak grids or areas with high photovoltaic penetration. It also enables functionalities such as islanded operation and black start capability, nevertheless the island operation is only partially practical in real-world distribution networks and require further validation.

ANALYSIS

The integration of grid-forming units demands new protection concepts, control logic, and clear regulatory guidelines. Moreover, the coordination of such units remains an open question: should individual DSOs be responsible, or should this fall under the remit of a central system operator? The procurement of grid-forming services also requires clarification, whether through market-based mechanisms or predefined obligations in grid codes. Both platform-based and tender-based models are currently under discussion, each with implications for transparency, efficiency, and long-term planning. In this paper a methodological approach is used for the analysis and impact of grid-forming into specific distribution network areas. The analysis deals with the stability of the power converter interactions at different points of the network to determine its impact on the distribution level. The selected areas are shown in Figure 1(a) and Figure 1(b). In addition, the positive influence of grid-forming on the PCC voltage within the grid sections is being investigated.

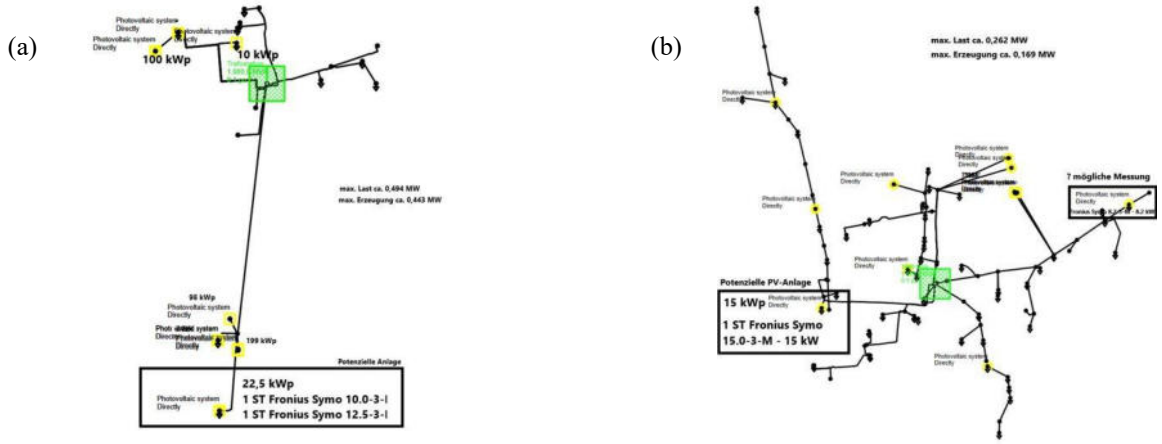


Figure 13: Distribution network (a) low-voltage network with industrial consumers and high PV density (b) typical low-voltage network with households (PSS Sincal + Matlab - Simplus Grid Tool)

To assess the stability of the grid-forming functionality different test cases have been considered, different load scenarios, different grid strength and different X/R ratio. In this regard, formal analysis over the GFM functionalities will be methodologically presented, especially considering the islanding events, black-start capacities and voltage regulation coordination amount multiple units.

REFERENCES

[1] https://www.europarl.europa.eu
[2] P. Rodríguez, C. Citro, J. I. Candela, J. Rocabert, and A. Luna, “Flexible Grid Connection and Islanding of SPC-Based PV Power Converters,” IEEE Trans Ind Appl, vol. 54, no. 3, pp. 2690– 2702, 2018, doi: 10.1109/TIA.2018.2800683

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
1.12. Next-Generation Technologies for Renewable Energy and Resource Efficiency

OPTIMAL OPERATION OF A SELF-REGULATING SMART DISTRIBUTION SYSTEM

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SUMMARY

Demand Response (DR) schemes improve grid reliability and save operating costs by incentivizing consumers to switch or reduce their electricity consumption during peak hours. DR programs are crucial for preserving the balance between supply and demand because they offer consumers incentives to change how much energy they use. To integrate renewable energy generation, loads, and corresponding DR control strategy as efficiently as possible while considering the intricate relationships between an electrical distribution network and grid resources, optimal operation and management in a quasi-steady-state simulation environment require strong global optimization techniques, such as distribution load flow simulations. To increase the responsiveness and effectiveness of DR systems, this research suggests a unique hybrid optimization methodology for smart grid DR systems that combines machine learning with a hybrid optimization tool. The findings show notable gains in customer engagement and grid performance. The suggested optimization technique reduced hardware cycling and maintained a smooth response to changing power needs. Additionally, it performed effectively by reducing power loss as much as feasible. The suggested optimization method also produced notable improvements in load balancing.

INTRODUCTION

This development calls for innovative solutions to preserve grid reliability, economic viability, and environmental sustainability. Among these strategies is Demand Response (DR), which encourages consumers to adjust their electricity consumption in response to price signals or grid conditions and has emerged as a crucial instrument for balancing supply and demand. However, developing robust optimization frameworks that can manage a variety of customer behaviors, fluctuating energy prices, and real-time grid constraints is essential to the effectiveness of DR programs. A real-time load flow control method is suggested for power distribution system operation to manage varying electric loads as DR resources (Callaway and Hiskens, 2011; Callaway, 2009). By encouraging a more reliable power supply with less distribution losses and a larger use of variable renewable energy sources, the method lowers greenhouse gas emissions and boosts energy efficiency. Due to the widespread usage of heat pumps and other heating loads, the output variability of renewable energy (RE) is being reduced, allowing for a greater penetration of RE without compromising power quality or dependability or adding burdens to power system ancillary services. Heat pumps are categorized as typical house loads and are a grid-friendly DR resource that is managed using a comfort-constrained DR control technique (Parkinson et al. 2011 and Parkinson et al. 2012). The integrated grid model and control algorithm optimize the actual working points of all heat pumps to provide the lowest power loss distribution load flow, hence satisfying customer comfort requirements. This integrated model was used to assess possible DR management strategies on a minute-by-minute time scale, when the production of renewable energy (sun, wind) may fluctuate significantly. The combined model is complex, computationally demanding, nonlinear, and nonunimodal. Without optimization, a worldwide self-adaptive optimal solution could not be developed by human modification and simulation. Commonly used stochastic global optimization search strategies may be very costly to compute, and standard optimization search techniques cannot find globally optimal solutions without extensive testing. A trustworthy and efficient global optimization search method that can manage big and intricate network simulation models is required to find the globally optimal control solution for the recently suggested hierarchical simulations.

LOWER-LEVEL COMFORT-CONSTRAINED DR CONTROL STRATEGY

The schematics of the hierarchical smart grid control architecture, which incorporates home heat pump management and a self-regulating distribution system with wind energy, are shown in Figure 1. The top level

creates a distribution system with an efficient power flow (or phases) by integrating wind energy and connecting dispatchable loads at three-phase distribution nodes. A load aggregator (LA) uses a lower-level comfort-constrained DR control technique to aggregate the dispatchable load form. A load aggregator is a population dynamics management model that uses the DR control technique for demand-side resources in its most basic form (Parkinson, 2012). It can also be used to link demand-side data to system optimization at a higher level and oversee implementation at a lower level.

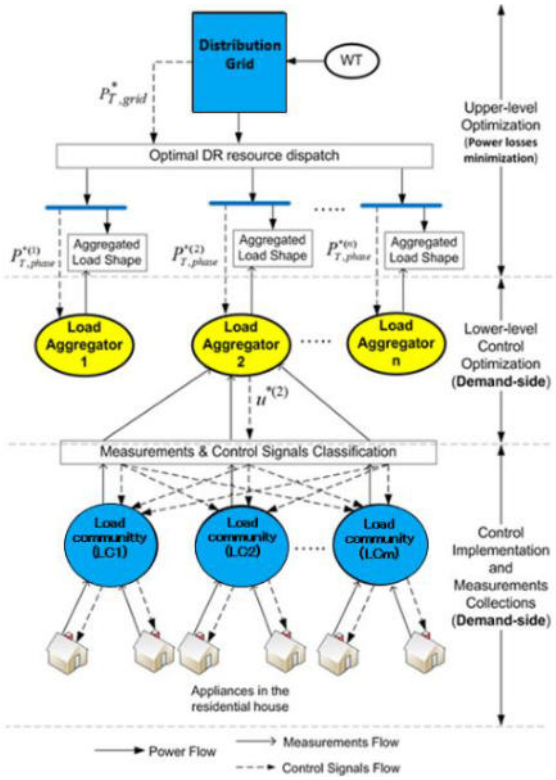


Fig 14: Basic hierarchical schematic of grid resource optimization in a smart self-regulating distribution system

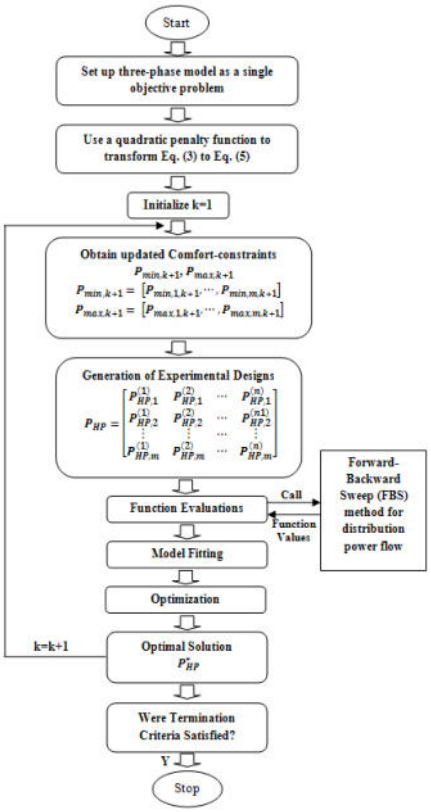


Fig 2: MMGO-based distribution optimal power flow algorithm flowchart

The optimization problem of upper-level grid resource control and dispatch can be expressed using the ideal power flow:

$$\min P_{loss}\,(\mathbf{V}, \boldsymbol{\theta}, P_{HPi}) \qquad \text{(eq. 1)}$$

Subject to:

$$g(\mathrm{V}, \theta) = 0 \qquad \text{(eq. 2)}$$

$$P^{*}_{T,grid} = \sum_{i=1}^{N} P_{HPi} + P_{other} + P_{loss} - P_{w} \qquad \text{(eq. 3)}$$

$$P_{min,k} \le P_{HPi} \le P_{max,k} \qquad \text{(eq. 4)}$$

where: The Forward-Backward Sweep algorithm implements a set of three-phase load-flow equations called g. The objective function, system power loss, is represented by P_{loss}. The state variable vector, three-phase nodal voltage amplitude, and phase angle are represented as $\boldsymbol{V}$ and $\boldsymbol{\theta}$, res. actively. P_{HPi} signifies the dispatchable load as a control variable vector, and it represents the ith heat pump power injections gathered in the i^{th} load aggregator. The operational comfort constraints of the i^{th} heat pump group are provided by the lower-level comfort-constrained DR control method, $P_{min,k}$ and $P_{max,k}$. Lighting, plug-in loads, and other unresponsive loads are included in residential buildings as P_{other}. P_w denotes wind power injection, while $P^{*}_{T,grid}$ denotes the overall power demand for the entire feeder based on upstream grid requirements. The countering impacts of wind changes are reflected in this constant tie-line power flow objective N. To solve equation (3), a pseudo penalty term is added to the objective function, yielding the modified objective function:

$$\mathrm{F} = P_{loss}\,(\boldsymbol{V}, \boldsymbol{\theta}, P_{HPi}) + K\left(P^{*}_{T,grid} - \sum_{i=1}^{N} P_{HPi} + P_{other} + P_{loss} - P_{w}\right)^{2} \qquad \text{(eq. 5)}$$

To ensure that the selected P_{HPi}values push the entire quadratic penalty term mentioned in equation (5) to zero, the pseudo penalty term K must be carefully determined, and it is usually a substantial amount. The quadratic term incorporates both limits and a stepwise update of the power target, hence it is neither a real Lagrange augmentation nor an alternate direction multiplier technique. Both other requirements in equations (2) and (4) are met simultaneously. We've been employing equation (6)'s dynamical tie-line power target instead of equation (5)'s constant tie-line power flow target (3).

$$P^*_{t,grid}[k+1] = \frac{P^*_{t,grid}[k] + P^*_{t,grid}[k-1]}{2} \qquad \text{(eq. 6)}$$

Therefore, the new optimal solution P_{HPi} should satisfy both the minimization of system power loss and the dynamical $P^*_{t,grid}[k+1]$ in each time step. The dynamic $P^*_{t,grid}[k+1]$ target offsets and reduces the load flow fluctuations, helping improve the optimal system operation. As shown in Figure 1, the data for the optimization process came from a semi-distributed rather than centralized control strategy, in which each LA receives individual load regulation signals, P_{HPi} from equations (1) - (4), as well as satisfying the heat-pump population operating comfort constraints determined by equation (4). P_{HPi} is communicated to the residential heat set point regulation signal, $u^*$by a DR program installed in the LA for each heat pump group. The receiving, u^* regulatory signal causes all heat pump devices in the various load communities (LC) indicated in Figure 1 to modify their machine states.

THE OPTIMIZATION ALGORITHM

The method fits the surrogate models over the identified region after exploiting and exploring the design region, utilizing extra design experiment data points from Latin Hypercube Designs to gain prior knowledge of the high-fidelity function. The performance of each model is then used to adjust the weights, and an ensemble surrogate model using chosen candidate points is produced. The combined surrogate is used to sample and evaluate the decision variable points in order to optimize them when the termination condition is satisfied. The global solution is eventually reached by the method's convergence. A flowchart for an MMGO-based distribution optimal power flow approach is shown in Figure 2. A load flow analysis of the IEEE Case 13 distribution grid model using Grid Lab-D [6] provides the input control data that is subsequently optimized. A fast-execution FBS code is called often in the MMSGO

RESULTS

Table 1 compares the unoptimized (Un-Opt.) and optimized (Opt.) power results using MMSGO (surrogate-based optimization algorithm, referenced also as Optimized or Opt.). Table 1 also compares the results of the un-optimized, MMSGO, GA, and SQP simulations using the same input data. When comparing simulation methodologies, both the mean and the standard deviation must be considered. The advantage of applying global search optimization approaches in optimizing SG models is demonstrated in Table 1 by the estimated power mean and STD results. Overall, the results demonstrate that MMSGO outperforms GA and SQP in terms of limiting grid fluctuations (lower STD values), but power loss is nearly identical for each simulation.

Table 1: Comparison of obtained un-optimized and optimized results

Power Criteria	(Un-Optimized)		MMSGO (Opt.)		GA (Opt.)		SQP (Opt.)	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Power loss	3795	54.6	3482	44.9	3750	76.8	3747	103.1
Power Target	6884	411.8	8760	184.3	6449	706.9	6418	1012
HP Sum	1833	385.7	2540	233.0	1450	538.2	1424	835.1
Power Loss Reduction %	---	---	+0.72	-12.4	-1.2	+40.7	-1.3	+88.8

Throughout the time sequence, the overall power loss for MMSGO and non-Opt simulations is rather steady; however, the non-Optimization changes in magnitude more than the MMSGO optimization (it fluctuates and varies sharply). The power losses of the GA and FMC are somewhat different, beginning out tiny but quickly increasing as they lose their ability to establish acceptable set points for the HPs, as can be seen in Figure 3.

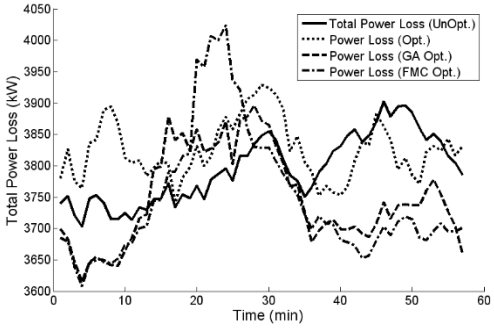


Fig. 3: Total power loss comparisons for un-optimized and optimized cases

CONCLUSION

This study presents a novel hybrid optimization framework for smart grid DR systems, integrating machine learning and a hybrid optimization tool. The results indicate substantial improvements in grid performance and consumer engagement. The optimization tool used kept the response to the power demand smooth and minimized hardware cycling while responding to altering power demands. It also worked well by minimizing power loss to the greatest extent possible.

REFERENCES

[1] Callaway, D., and Hiskens, I., (2011), Achieving controllability of electric loads. Proceedings of the IEEE, vol. 99, no. 1, pp. 184 –199

[2] Callaway, D., (2009), Tapping the energy storage potential in electric loads to deliver load following and regulation, with application to wind energy. Energy Conversion and Management, vol. 50, no. 5, pp. 1389 – 1400, 2009.

[3] Parkinson, S., Wang, D., Crawford, C., and Djilali, D. (2011), Comfort-constrained distributed heat pump management. Energy Procedia 12, pp.849 855

[4] Parkinson, S., Wang, D., Crawford, C., Djilali, N. (2012), Wind integration in self-regulating electric load distributions. Energy Systems. 3. 10.1007/s12667-012-0060-2.

CONFERENCE TOPIC

Smart energy infrastructure for Energy transition

INTEGRATED ENERGY SOLUTIONS FOR SUSTAINABLE PORT DEVELOPMENT

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SUMMARY

This study explores integrated sustainable energy solutions for the Swiss Rhine inland port in Basel which is administrated by the Port of Switzerland (POS). POS is the national transport hub on the Rotterdam-Basel-Genoa freight transport corridor, provides the infrastructure for cargo handling activities and ensures that the port remains an attractive logistics location in the future. Our study focusses on techno-economic and ecological developments and benefits in the framework of an extension of the port and specific interests of port companies which comprise the security of energy supply and the use of renewable energy for decarbonization. The challenge therefore is to maximize energy self-consumption by local renewable energy production, possibly including a commonly used sustainable energy infrastructure in the port area. By this, POS should at the same time contribute to Basel's ambitious climate goals (net zero by 2037).
In one of the first steps, the total energy consumption of the port activities was estimated to be about 9.1 GWh including electricity, heat, and mobility. Based on several assumptions regarding the extension of port activities, it is expected to increase to 9.5 GWh by 2030. The port companies emitted 1,500 tons of CO_2 equivalent in 2023. This paper analyses and proposes different scenarios to use surplus PV energy to significantly reduce fossil fuels in the heat and mobility sectors. This can be achieved by implementing power-to-heat technologies, electric vehicle charging infrastructure, and corresponding energy storage systems.

INTRODUCTION

The project called “Green Port”, in collaboration with POS, aims to create a networked and largely self-sufficient energy system for the inland Rhine port of Kleinhüningen in Basel. This initiative seeks to maximize the utilization of renewable energy sources generated on-site and promote local energy consumption through electricity, fuel, and heat. The project envisions a cooperative business model for energy production and consumption, focusing initially on the Kleinhüningen location.

The project involves different phases, starting with a demand and potential analysis, followed by an analysis of potential implementation models. The demand analysis includes estimating the overall energy demand and its distribution throughout the year, based on collected data. The potential analysis includes existing studies to identify further potentials. The implementation model analysis focuses on understanding and combining stakeholder interests and needs, exploring technical solutions, and establishing an organizational framework for the implementation of the project results.

ANALYSIS OF CURRENT SITUATION AND POTENTIAL

As pointed out in the introduction, the integrated solutions must fulfil several expectations in order to develop the port area in accordance with the needs of the stakeholders (mainly POS, port companies, city of Basel). Furthermore, the needs have technical and economic parts within an ecosystem aiming at low to zero emissions. Through interviews and surveys, "gains and pains" of different stakeholders have been evaluated, revealing a strong interest in comprehensive energy solutions and collaboration. The port operator POS together with the

companies in the port aim to increase local renewable energy production to the maximum and to find ways to collectively benefit from existing PV surplus energy to foster a sustainable future of both the companies and the port. By this, the port will contribute to the ambitious climate goals of the city council in Basel.
A quantitative analysis presented in Fig. 1 indicates a current energy demand of 9.1 GWh at the port, comprising 4.1 GWh electricity, 2.5 GWh total heat, and 2.5 GWh for land vehicles. It was decided not to include the energy demand of container or passenger ships in this part of the study. This energy demand described is projected to increase to 9.5 GWh by 2030 due to an already planned port transformation, with a shift from current heat and fuel needs towards electricity, mainly driven by additional cargo crane installations, substitution of fossil fuels for heat generation, and electrification of transport. PV has been examined in detail for energy production whereas other local renewable energy production options (such as wind, solar thermal etc.) were excluded based on feasibility or yield assessments from former studies. The full deployment of PV on all possible roofs and facades could potentially generate 9.8 GWh (data for yearly PV energy production was taken from the database of the Swiss Federal Office of Energy *Sonnendach* [1] and *Sonnenfassade* [2]), meeting the expected port's energy needs on a balance sheet basis.
As of 2023, port companies emit approximately 1,500 tons of CO_2 equivalent (calculations based on GHG protocol standards with sources [3]-[5]), primarily from fossil fuel use in land vehicles as well as natural gas and heating oil for heat production as presented in Fig 1. To significantly reduce CO_2 emissions in the port area, it is crucial to replace fossil fuels used for heat and transport with renewable energy.

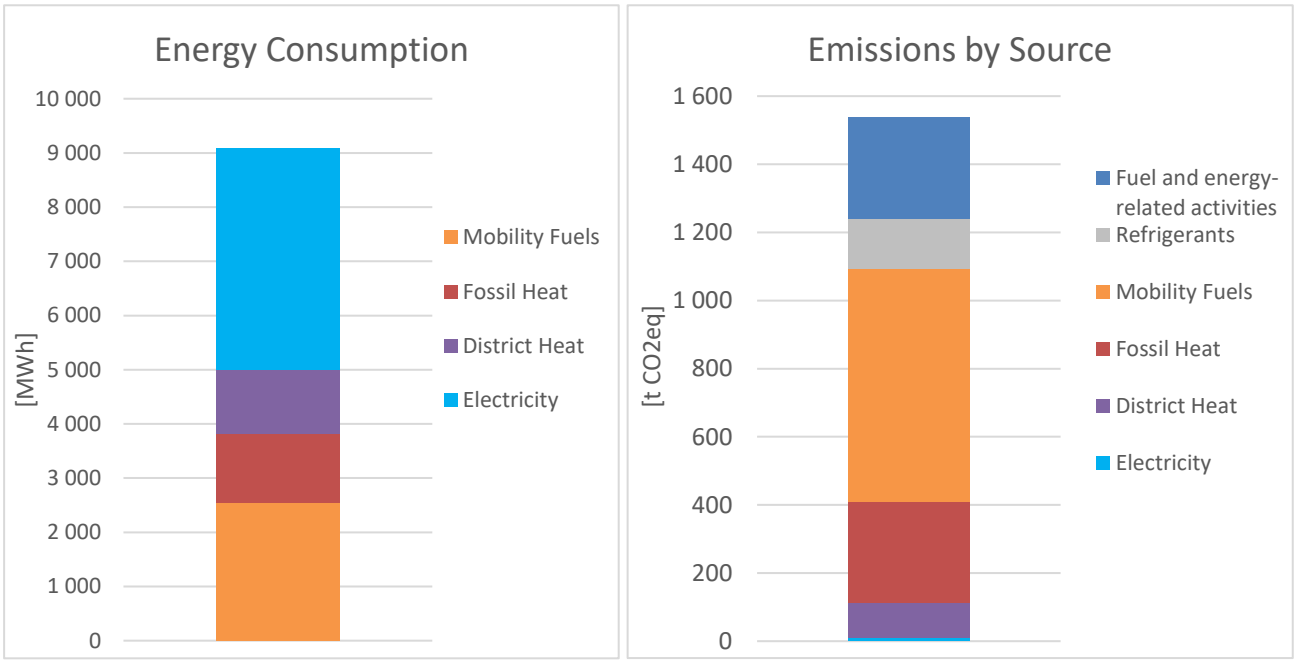


Fig. 1: Energy consumption (left) and CO2(e) emissions by source (right) on the port area caused by the port companies in the year 2023

INTEGRATED ENERGY SOLUTIONS AND CONCLUSIONS

The contribution will present the current situation of the port area and the comparison of different options for transforming the Port of Switzerland towards climate neutrality until 2037. The full paper will present realistic scenarios which propose technical aspects how to potentially develop an economic and ecological integrated energy infrastructure at the Rhine port in Basel. The options investigated and compared comprise utilizing surplus PV energy for heat supply through heat pumps and/or a power-to-heat concept as well as batteries. All options should cover the needs of the whole port area in an optimal way. The options are investigated on a concept level both technically and economically. Heat pumps could, for instance, use the new harbour basins as a heat source.

Expanding district heating usage is another option since a district heating net exists nearby. Additionally, developing a networked electric charging infrastructure is feasible. According to federal studies, transport electrification is imminent. With effective load management supported by electrical storage, self-consumption could be increased, and transport decarbonized. For the electrification of transport, both trucks and the port railway need to be considered more closely. Summarizing, the study reveals several relevant insights on the development of integrated energy solutions for sustainable port development under multi-stakeholder conditions. The presentation at ISEC 2026 intends to create an opportunity to discuss the following aspects at the conference: How can smart energy infrastructure be conceptualized effectively and efficiently to contribute to the energy transition, how can energy sectors in areas such as ports be coupled, how can commonly used infrastructure in industrial areas be operated and used for increased flexibility and stability of local grids, how can business models look like that enhance and support the development?

REFERENCES

[1] Sonnendach. “Swiss Federal Office of Energy SFOE website”. https://www.uvek-gis.admin.ch/BFE/sonnendach/?lang=en (accessed 23.07.2025)

[2] Sonnenfassade. “Swiss Federal Office of Energy SFOE website”. https://www.uvek-gis.admin.ch/BFE/sonnenfassade/?lang=en (accessed 23.07.2025)

[3] Department for Energy Security and Net Zero (2023) Greenhouse gas reporting: conversion factors 2023. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2023.

[4] IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (R. K. Pachauri & L. A. Meyer, Eds.). Geneva, Switzerland: IPCC, 151 pp.

[5] Volkart, E., Nauser, I. K., & Alig, M. (2024). Treibhausgas-Emissionsfaktoren für den Gebäudesektor: Bestimmung von Emissionsfaktoren nach den Bilanzierungsregeln der KBOB und des GHG-Protocols (Version 2.0). Zürich: intep – Integrale Planung GmbH.

INNOVATIVE BATTERY STORAGE STRATEGY AND TECHNOLOGY DEVELOPMENT

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SUMMARY

Austria's energy transition is driving demand for flexible and scalable electricity storage, with battery energy storage systems (BESS) playing a central role. Wien Energie, alongside Wiener Energiespeicher GmbH (WESP), is developing diverse BESS configurations to support grid stability, decarbonization, and renewable integration. Utility-scale, co-located, and behind-the-meter systems are being deployed, with lithium-ion batteries currently leading. A strategic research approach evaluates emerging technologies like redox-flow batteries through pilot projects. Wien Energie's long-term strategy combines innovation, market integration, and collaboration to build a secure, low-carbon energy system aligned with Vienna's 2040 climate goals.

INTRODUCTION

The decarbonization of the energy system is increasing the need for flexible, scalable, and economically viable electricity storage solutions. In Austria, the integration of battery energy storage systems (BESS) is becoming a cornerstone of the national electricity strategy, with projected demand rising from 69 TWh in 2024 to 90 TWh by 2040. As Austria's largest regional energy provider, Wien Energie is actively shaping the energy transition through a diversified portfolio of generation and storage assets. Our strategy includes the objectives to swiftly integrate renewable energy, enhance system flexibility, and leverage energy storage systems to support decarbonization and grid stability. Together, Wien Energie and Wiener Energiespeicher GmbH (WESP) —a subsidiary of Wien Energie GmbH and Wiener Stadtwerke GmbH— pursue a multi-faceted energy storage strategy to address Austria's rising electricity demand.

As one possible option, battery energy storage systems (BESS) are essential to balance fluctuations, absorb surplus generation, and support peak demand. While assets like CHP plants and hydropower offer fast ramping capabilities, they must be complemented by scalable and decentralized storage technologies to meet future system needs and fully unlock the potential of renewable energy. To address these challenges, Wien Energie and WESP are developing BESS in various configurations, including stand-alone, co-located, and behind-the-meter (btm systems, including assets for black start capability. While regulatory clarity, especially regarding applicable grid fees for energy storage, is crucial to accelerating investment, the project development is focused on the three main boundary conditions: grid access, land availability, and permitting. Utility-scale BESS generate revenues across multiple wholesale and ancillary service markets, thereby contribute on a systemic level, while the focus of co-location and btm solutions often lays on optimizing existing grid access and a diverse generation and consumption system of a customer. Large-scale batteries are expected to grow from 100 MW in 2024 to over 500 MW by 2040, while pooling solutions and behind-the-meter systems are gaining importance for market flexibility (i.e. demand response) and self-consumption.

TECHNOLOGY EVALUATION & INTEGRATION

Currently, lithium-ion batteries are at the forefront of implementation due to their high energy density, efficiency, and broad industrial availability. (IEA,2024)

Beyond current applications, the research department of Wien Energie pursues a strategic approach to the long-term evaluation and integration of emerging storage technologies. The goal is to identify innovative solutions at an early stage, assess them systematically, and test them in a targeted manner to enable rapid and efficient deployment. This process is based on a rigorous technology assessment framework that considers technical, economic, and safety criteria.

One key element of this strategy is a dedicated battery test skid, where new technologies at an early TRL (Technology Readiness Level) (Strazza, 2017). can already be evaluated at an early stage under intended operating conditions. Promising Technologies that move to the pilot and demonstration level can further be assessed in a first pilot field deployment. A particularly promising alternative storage concept such as redox-flow batteries (Lourenssen, 2019), which offer high cycle stability, fire safety, and flexible scalability will soon be tested in an advanced pilot project in the field to assess their practical viability and potential for large-scale deployment.

The research department collaborates closely with internal and external partners to identify technological developments early to acquire a systemic understanding of the role of storage in future energy systems and incorporate them into strategic planning.

Wien Energie positions itself as an active driver of the energy transition and the continuous advancement and integration of new storage technologies is a key factor in successfully implementing a long-term energy storage strategy.
Through innovation, market integration, and collaboration, we are building the infrastructure needed for a flexible, secure, and low-carbon energy system that supports Austria's 2040 climate goals.

REFERENCES

IEA (2024), Batteries and Secure Energy Transitions, IEA, https://www.iea.org/reports/batteries-and-secure-energy-transitions (last accessed 05 September 2025), Paris, France

Strazza, C., Olivieri, N., De Rose, A., Stevens, T. et al, (2017) Technology readiness level – Guidance principles for renewable energy technologies – Final report, European Commission: Directorate-General for Research and Innovation, Bruxelles, Belgium

Lourenssen, K., Williams, J., Ahmadpour, F., Clemmer, R., Tasnim, S., (2019) Vanadium redox flow batteries: A comprehensive review, Journal of Energy Storage, Volume 25

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: Building the Future: Smart Energy Infrastructure for the Energy Transition

UNDERGROUND THERMAL ENERGY STORAGE AND ITS IMPACT ON GROUNDWATER BASED ON EXPERIMENTAL MOCK-UPS

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SUMMARY

Heat storage systems are crucial for the energy transition, providing a more sustainable energy supply and mitigating peak demands, particularly in urban areas. Current developments focus on underground installations that use the subsurface for thermal storage, to reduce land use and sealing. However, these structures are impacting the subsoil and the groundwater, potentially degrading drinking water quality and therefore complicating the approval procedure and construction of underground thermal energy storages (UTES). This paper introduces a controlled experimental concept for analysing the effects of UTES on aquifers. Previous research primarily relies on numerical modelling, which offers limited legal validity for project approvals but serves as a foundation for optimization and monitoring strategies. The proposed approach reproduces the formation of thermal plumes as a function of hydraulic gradient, soil permeability, and storage design. In addition, a simplified construction method is presented to facilitate urban heat storage system implementation.

URBAN THERMAL UNDERGROUND ENERGY STORAGES

Changes caused by climate change, such as the extremely critical overheating in summer and the resulting heat islands, especially in urban areas [1], pose an acute threat to the human habitat and thus to the quality of life. One contribution to mitigating the progression of climate change is the use of sustainable and green energy and heat sources such as solar, wind and photovoltaics. However, the positive increase in the number of sustainable primary energy generators is increasingly raising the question of how the surplus energy generated can be stored temporarily. The lack of solutions for storing thermal energy, which is also generated in the form of industrial waste heat or waste heat from cooling operations, for example, means that this energy is emitted unused into the environment and is therefore wasted [2]. Efforts to develop new heat storage options, as described in [3] [4], aim to use the subsurface as a storage medium or to establish underground storage facilities.

Despite the long history of heat storage tanks, they are rarely used in urban areas due to a lack of space and complicated manufacturing processes. Primarily driven by the complex construction of heat storage tanks in very limited space and the risk of damage to existing buildings in the immediate vicinity as well as the impact on groundwater, which - at least in a European context - is often a sensitive source of drinking water.

For this reason, a research project is investigating the implementation of a storage solution that is easy to produce and, above all, can be integrated within the city centre. In addition to considering existing urban infrastructure, the main aim is to be applicable to the widest possible extent and to cover the heat requirements of existing buildings or to integrate existing heat sources and cover peaks in heat demand while fulfilling emission criteria.

TEST SETUP AND CONCEPTS

In order to demonstrate the effects of urban heat storage, a modelled simulation of the heat flow underground is being carried out as part of a project that deals with this topic as a whole. A diagram of this is shown in Fig. 1.

A thermally insulated trough is used to model the subsurface and associated groundwater body within a confined, reproducible domain. The subsoil is represented by a sand-gravel body with a maximum grain size of 4 mm,

which is placed in layers with low compaction. A distributed fiber optic sensing system is installed on five horizons in the course of the placement, which records temperature changes in the subsoil with a local resolution of 5 cm. To simulate a groundwater flow, a permeable distributor wall is installed at the boundaries of the soil body, which serves to ensure a laminar flow through the soil body with a specifically applied hydraulic gradient.

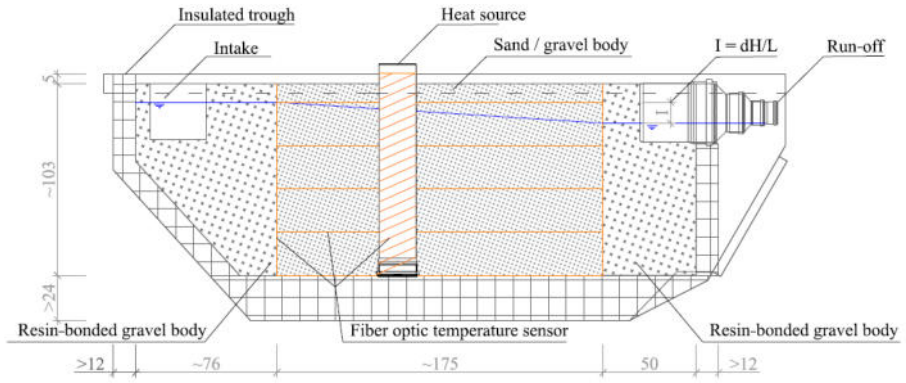


Fig. 5: Schematic of the test setup to simulate groundwater influenced by a thermal underground storage

The heat source is represented by a vertical pipe that interacts with the surrounding soil body and can be subjected to different charging and discharging cycles and temperature levels.

Adjustments to the pipe material and horizontal separation enable control of the tank properties and thermal zoning, while the permeability of the subsoil is controlled by targeted compaction and hydraulic gradient changes can be made between test phases. The main objective is to obtain a valid and reproducible representation of the heat distribution in the subsoil and thus to provide a basis for the calibration of numerical analyses and constitutive models to contribute to technical and economic considerations of UTES in urban areas. A major challenge in these tests lies in modelling and scale effects, which complicate both hydrological analysis and geotechnical evaluation.

This article is intended to show the initial results from the series of tests, illustrate their limitations and subsequently demonstrate the potential for analytical and numerical simulations in this area. With regard to the increasing demand for heat storage solutions in urban areas, the utilisation of these in existing buildings and the possibilities they offer for integrating heat islands as heat sources, for example, such studies can be used as a basis for decision-making in order to be available to authorities and operators.

REFERENCES

[1] Ward, K., Lauf, S., Kleinschmit, B., & Endlicher, W. (2016). Heat waves and urban heat islands in Europe: A review of relevant drivers. Science of the Total Environment, 569, 527-539.

[2] Borri, E., Zsembinszki, G., & Cabeza, L. F. (2021). Recent developments of thermal energy storage applications in the built environment: A bibliometric analysis and systematic review. Applied Thermal Engineering, 189

[3] Alva, G., Lin, Y., & Fang, G. (2018). An overview of thermal energy storage systems. Energy, 144, 341-378.

[4] van Helden, W. et al. (2021). Saisonale Speicher zur Erhöhung des Anteils erneuerbarer Energien für Distrikte. Final report–giga_TES-project.

CONFERENCE TOPIC

1.15 Sustainable Renovation and Energy Retrofits

LEAVE NOONE BEHIND. VULNERABLE PEOPLE AND ENERGY COMMUNITIES. FIRST INSIGHTS

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SUMMARY

This abstract presents two projects EWV4Energiewende and GENDER4POWER, which both investigate how renewable energy communities (RECs) can be implemented in dense urban areas as part of a holistic approach to the urban energy transition. Working across seven properties of the *Evangelischer Waisenversorgungsverein Wien (EWV),* the project combines technical and social analyses to identify barriers, potentials, and tailored solutions, translated into site-specific roadmaps. One of the project's pilot buildings, the therapeutic centre *Schweizer Haus Hadersdorf (SHH)*, demonstrated how targeted energy literacy workshops and capacity-building activities enable the inclusion of groups vulnerable to energy poverty. The project's outcomes provide transferable knowledge for policy, research, and practice, contributing to climate-neutral and socially inclusive urban development.

INTRODUCTION

The climate and energy crises present global, national, and municipal challenges that affect governance, the economy, and daily life of communities. Rising energy costs disproportionately impact low-income households (Wegscheider-Pichler, 2021). High energy expenditures, limited resources, and inefficient housing with poor energy performance push many into energy poverty (Middlemiss, 2022), where households reduce energy use to levels harmful to health and wellbeing (European Commission, Directorate-General for Energy, 2025). Gender further shapes vulnerability: women are disproportionately affected, as inequalities in income, caregiving roles, housing security, and domestic power dynamics can increase exposure to energy-related hardship (Pachauri & Rao, 2013; Petrova & Simcock, 2021). Addressing the energy crisis therefore requires recognising and tackling these social dimensions.

URBAN RENEWABLE ENERGY COMMUNITIES: OPPORTUNITIES AND BARRIERS

Urban renewable energy communities (RECs), promoted under the European Green Deal (European Commission, 2019) and Austria's Renewable Energy Expansion Act (Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology, 2021), can support decarbonisation, energy security, and social cohesion. Yet in dense urban contexts, they face legal restrictions, complex ownership structures, limited renewable installation space, and high upgrade costs. Social factors, such as low awareness, perceived complexity, and limited investment willingness in rental settings, further limit uptake (Sen & Ganguly, 2017; Nic Aoidh et al., 2019; Fischer et al., 2024). Overcoming these barriers demands approaches that combine

technical innovation with inclusive, gender-sensitive engagement, ensuring that the energy transition benefits all. Within this context, the project *EWV4Energiewende – Contributions to the urban energy transition using the example of the properties owned by the Evangelischer Waisenversorgungsverein Wien (EWV)* [4] and *GENDER4POWER. Generating Equity, Nurturing Diversity, Energising Resilience 4 Power Against Energy Poverty* were launched to address these barriers, presenting a just and inclusive approach to sustainable urban energy.

THE PROJECTS' APPROACHES TO OVERCOMING BARRIERS

Across seven properties owned by the EWV, the project assesses the feasibility and potential for expanding renewable energy and creating RECs in dense urban areas. The EWV is a charitable, church-affiliated association supporting children and adolescents in difficult life situations and promotes the energy transition across its portfolio. The project focuses on identifying personal, organisational, and structural barriers that limit participation in community renewable generation and developing practical solutions to overcome them. Technical and social potential analyses are combined with a participatory approach involving interviews with experts, property owners, and residents. Co-creative processes supported by interactive tools help identify stakeholder interests, facilitate joint decision-making, and design incentive models that increase acceptance of integrated technical and social solutions. A multidisciplinary project team ensures that technical, social, and legal perspectives are integrated, while targeted communication strategies maintain engagement with all stakeholders. By the project's end, building- and block-specific implementation plans will be produced, including economic comparisons, opportunities, and risks, with recommendations for renewable energy adoption and REC participation.

GENDER4POWER DEMONSTRATOR: INCLUSION OF VULNERABLE GROUPS AT SHH

A particular focus of the project lies on the Schweizer Haus Hadersdorf (SHH), a non-profit therapy facility for addiction disorders located on EWV premises in Vienna's 14th district. SHH serves as a pilot case to demonstrate how groups vulnerable to energy poverty can be actively included in the energy transition. Many residents face limited income, insecure housing, and health challenges, combined with poor building energy performance, which heightens their vulnerability. At SHH, technical analysis explores renewable energy potential and REC integration, while targeted capacity-building activities address energy literacy in accessible, gender-sensitive ways tailored to the therapeutic context. Knowledge-transfer and awareness-raising workshops engage patients in energy-saving practices, energy community participation, and broader climate topics. These activities respond to observed everyday behaviours, such as prolonged device use, unnecessary lighting, and heating with open windows, highlighting the need for behavioural change alongside technical measures. By linking infrastructure improvements with empowerment, SHH demonstrates how social institutions can act as trusted intermediaries, reaching those often excluded from energy initiatives and strengthening social equity.

CONCLUSION AND OUTLOOK

Both projects demonstrate that establishing RECs in dense urban areas requires an integrated approach combining technical assessment, co-creative design, and inclusive, gender-sensitive engagement. Working across diverse properties, it generates practical insights into the potentials and limits of urban renewable expansion, as well as the organisational and behavioural factors shaping participation. Results will be compiled into implementation roadmaps for each property, outlining economic comparisons, risks, and tailored recommendations. The SHH case study highlights how linking technical solutions with targeted capacity-building can effectively include vulnerable groups in the energy transition. The resulting knowledge base captures success factors and

[4] Project title translated from German

participation barriers in the urban energy transition and provides guidance for future projects, inspiring other property owners to expand renewables and establish or join RECs. In doing so, EWV4Energiewende supports climate-neutral urban development and ensures the benefits of the energy transition are accessible to a broad, diverse urban population.

REFERENCES

European Commission, (2019), Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions – The European Green Deal (COM (2019) 640 final). EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0640

European Commission, Directorate-General for Energy, Energy Poverty Advisory Hub (EPAH), Biondani, D., Gouveia, J. P., Garcia, M., (2022), Energy Poverty Advisory Hub (EPAH) Handbook. Publications Office of the European Union, Brussels, Belgium. https://op.europa.eu/en/publication-detail/-/publication/c8904e14-5d37-11f0-a9d0-01aa75ed71a1/language-en

Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology, (2021), Bundesgesetz über den Ausbau von Energie aus erneuerbaren Quellen [Renewable Energy Expansion Act – EAG], Federal Law Gazette I No. 150/2021. Legal Information System of the Republic of Austria (RIS). https://www.ris.bka.gv.at/Dokumente/Erv/ERV_2021_1_150/ERV_2021_1_150.pdf

Fischer, H., Haas, R., Ajanovic, A., & Radosits, F., (2024), Energiegemeinschaften – Eine Evaluierung bisheriger Erfahrungen und zukünftiger Perspektiven für Österreich. Wien, Österreich. https://energiegemeinschaften.gv.at/wp-content/uploads/sites/19/2024/05/EnComm_Endbericht_Fertig.pdf

Middlemiss, L., (2022), Who is vulnerable to energy poverty in the Global North, and what is their experience?, Wiley Interdisciplinary Reviews: Energy and Environment, 11(6), e455.

Nic Aoidh, A., Hülsken, C., Good, C., Ó Neachtain, E., Elfgren, E., Ó hOgáin, F., Ruuska, H., Risberg, M., Nic Suibhne, O., Leonard, P., Etelamaki, P., Fischer, R., Kajimura, R., Herrmann, S., Müller, U., & Mehl, W., (2019), PESTLE analysis of barriers to community energy development. LECo – Northern Periphery and Arctic Programme. https://leco.interreg-npa.eu/subsites/leco/PESTLE_Analysis_LECO_A4_190110-singlepages.pdf

Pachauri, S., & Rao, N. D., (2013), Gender impacts and determinants of energy poverty: Are we asking the right questions?, Current Opinion in Environmental Sustainability, 5(2), 205–215.

Petrova, S., & Simcock, N., (2021), Gender and energy: Domestic inequities reconsidered, Social & Cultural Geography, 22(6), 849–867.

Sen, S., & Ganguly, S., (2017), Opportunities, barriers and issues with renewable energy development – A discussion, Renewable and Sustainable Energy Reviews, 69, 1170–1181.

Wegscheider-Pichler, A., (2021), Erweiterte Betrachtung der Energiearmut in Österreich – Hohe Energiekosten bzw. Nicht-Leistbarkeit von Energie für Wohnen. Statistik Austria, Wien, Österreich. https://www.statistik.at/fileadmin/publications/Erweiterte_Betrachtung_der_Energiearmut_in_OEsterreich_2018.pdf

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: Transform Cities: Holistic Approaches to Sustainable Urban Energ; Just and inclusive mechanism for the energy transition

SAF-ORIENTED PUBLIC POLICIES AND THEIR SOCIAL DIMENSION: AN AHP APPLICATION TO THE CASE OF BRAZIL

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SUMMARY

Policies to boost the production and consumption of Sustainable Aviation Fuel (SAF) are naturally reasoned by environmental issues, but they may lack other sustainable goals, especially those related to social concerns. In this study, we evaluate SAF public policies in Brazil and the EU, specifically examining their alignment with Environment, Social and Governance (ESG) dimensions. A two-stage methodology is employed: first, we conduct a comparative analysis to benchmark the SAF policy strategies in the EU and Brazil; and second, we apply an Analytic Hierarchy Process (AHP) model to assess the extent to which these policies incorporate ESG criteria. Preliminary results stress out different strategies: the EU follows a minimum share of SAF usage and Brazil a GHG reduction target. Besides, the EU is fully committed to upcoming plants based on e-SAF and Brazil on feedstocks that are derived from dedicated crops. The AHP application indicates that the social component remains as a challenge to be included in prospective public policies.

Keywords: SAF; ESG; Brazil; EU.

INTRODUCTION

SAF represents the leading solution to reduce greenhouse gas (GHG) emissions in the aviation industry, which accounted for 2.5% of global CO_2 emissions in 2023 (IEA, 2023). Policies to boost SAF production and consumption are naturally reasoned by environmental issues, but may lack other sustainable goals. In this context, ESG safeguards stand as a more comprehensive set of objectives that leads to a more effective, just and inclusive public policy. Furthermore, SAF production's alignment with United Nations (UN) Sustainable Development Goals (SDGs) 7, 9 and 13[5] can enhance its economic and social effectiveness, increasing consumers' acceptance.

In this regard, the International Civil Aviation Organization's (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) provides an extensive framework which sets up the fundamentals on how to conduct an environmentally and socially sustainable SAF policy (ICAO, 2022). Beyond environmental and social aspects, governance also plays a pivotal role. Public policies such as mandates, subsidies, and certification mechanisms are essential to ensure that SAF deployment is economically viable while promoting transparency, stakeholder participation, and equitable distribution of benefits - as highlighted in studies addressing the social and governance dimensions of biojet fuel supply chains (Arora *et al*., 2018).

The European Union (EU) is taking a major role in the effort to conceive public policies to stimulate SAF production that are compatible with ESG targets. These measures include enforcing mandates that prioritise

[5] SDG 7 — Affordable and Clean Energy; SDG 9 — Industry, Innovation and Infrastructure; and SDG 13 — Climate Action.

synthetic SAF (e-SAF), investing in production facilities, and developing a cap-and-trade system that benefits SAF implementation (EU, 2023). The focus on e-SAF is a strategic response to concerns over land use change (LUC) and its social and environmental impacts, which are major challenges for conventional SAF derived from biomass feedstocks.

Therefore, this study evaluates SAF public policies in Brazil and the European Union, specifically examining their alignment with ESG dimensions. To achieve this, a two-stage methodology is employed: first, we conduct a comparative analysis to benchmark the SAF policy strategies in the EU and Brazil; and second, we apply an AHP model to assess the extent to which these policies incorporate ESG criteria.

METHODOLOGY

The first methodological step is an international benchmarking analysis. Our main reference in terms of best practices of policy making is the EU, both the whole region and single countries' experiences. We compare the scope and the performance of selected EU policy measures and assess the viability of applying them to a developing country reality (Brazil). Policy instruments that comply with social targets – such as technological transfer, local development and involvement of small family farmers – are preferentially selected. Besides their ESG content, policy measures that are more easily adapted and financially effective are the ones most likely to be surveyed in the benchmarking analysis.

The second methodological tool refers to an AHP model, a widely used approach for estimating the weights of decision criteria based on expert judgment (e.g., Canco, Kruja, and Iancu, 2021). As pointed out by its original developer (Saaty, 1980), from a system of pairwise comparisons conducted by experts, it is possible to rank all available alternatives in the decision process.

The typical AHP problem follows a hierarchical structure. The first step is to set the main goal of the problem. Under that goal, criteria and, if needed, sub-criteria are defined. The last layer of the decision tree contains an evaluation of the choices in question. Applying to our case, the goal is to investigate the role of social features in public policies that are set to stimulate SAF. The criteria in the decision tree are the ESG dimensions while specific environmental, social and governance measures are the sub-criteria level. It is worth mentioning that all pairwise assessments are made by experts from transport regulation agencies and energy research institutes. Besides, ratifying one of the AHP advantages, we run the model with both quantitative and qualitative variables. Finally, the methodology provides a numerical value ranking all the alternatives; that is, a list of policy instruments and their respective achievements in terms of ESG content.

PRELIMINARY RESULTS

A preliminary evaluation of SAF public policies in the EU and Brazil reveals distinct approaches, which stem from their respective capacities for producing SAF feedstock. The EU's strategy pursues a 70% share of sustainable fuels by 2050, promoting both conventional SAF and e-SAF. This is exemplified by the ReFuelEU Aviation mandate, which requires a 0.7% share of e-SAF use starting in 2030, a 10% share by 2040, and a 35% share by 2050 (EU, 2023). In Brazil, SAF mandate is not related to any specific fuel usage, but rather GHG reduction, from 1% in 2027 to 10% in 2037 (Brasil, 2024). Besides, our findings ratify that the policy agenda in the EU is committed to the fact that most of the upcoming plants are based on Power to Liquid (PtL) technology, whereas in Brazil the policy agenda reinforces the competitive advantages of feedstock-based SAF plants (ICAO, 2025).

Indeed, in Brazil, the primary inputs for SAF production are mainly ethanol and soybean oil, which reflects the country's leadership in the production of sugarcane and soybeans. However, because these feedstocks are derived from dedicated crops, they yield a SAF product with a higher carbon intensity than fuels produced from residues or waste streams.

Finally, the application of an AHP model to rank policy measures to support SAF production considering their commitment to local social aspects indicates that policies are, first, connected to environmental targets and, second, are associated to governance-related issues such as ESG data transparency and compliance. The social component remains – according to policy makers judgement – less relevant and seen as a consequence of the

financial performance of the SAF production sector. Themes like the process of integrating small producers and traditional communities into the SAF supply chain, particularly with non-conventional feedstocks (e.g., macauba palm oil) remain a challenge for prospective public policies.

REFERENCES

Arora, S., Peña, N., Romeiro Filho, E., & Lopes, G., (2018), Towards social sustainability: Screening potential social and governance issues for biojet fuel supply chains in Brazil. Renewable and Sustainable Energy Reviews, v. 96, p. 386–400. Available at: https://www.sciencedirect.com/science/article/pii/S1364032118303009. Access on: 12 sep. 2025.

Brasil, (2024), Lei nº 14.993, de 26 de novembro de 2024. Diário Oficial da União, Brasília, BR.

Canco, I., Kruja, D., & Iancu, T, (2021), AHP, a reliable method for quality decision making, A case study in business. Sustainability, 13(24), [Basel], CH.

International Civil Aviation Organization (ICAO), (2022), CORSIA Sustainability Criteria for CORSIA eligible Fuels. [Montreal], CN.

International Civil Aviation Organization (ICAO), (2025), Production Facilities. Montreal, CA. Available at: https://www.icao.int/environmental-protection/SAF/Pages/Production-Facilities.aspx. Access on: 13 jun. 2025.

International Energy Agency (IEA), (2023), Aviation 2023. Paris, FR. Available at: https://www.iea.org/reports/aviation. Access on: 12 sep. 2025.

International Energy Agency (IEA), (2023), Aviation 2023. Paris, FR. Available at: https://www.iea.org/reports/aviation. Access on: 12 sep. 2025.

Saaty, T.L, (1990), The Analytic Hierarchy Process. RWS Publications, Pittsburgh, US.

European Union, (2023), Regulation (EU) 2023/2405 of the European Parliament and of the Council of 18 October 2023 on ensuring a level playing field for sustainable air transport (ReFuelEU Aviation). OJ L 2023/2405, Brussels, BE.

CONFERENCE TOPIC

2.03 Just and inclusive mechanism for the energy transition

NON-ENERGY BENEFITS OF ENERGY EFFICIENCY PROJECTS INSTRUCTION FOR ABSTRACTS

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SUMMARY

Non-Energy Benefits (NEBs) are a major strategic asset for energy efficiency. For more than 30 years, numerous studies have confirmed that NEBs significantly enhance the profitability and attractiveness of energy efficiency projects. Taking them into account makes it possible to better highlight the strategic impacts of these projects and motivate their adoption, providing benefits on several levels: economic, social and environmental.
However their potential is still largely untapped in analyses. Despite their recognised importance, NEBs factors remain little or not at all integrated into financial and decision-making analyses. Existing tools, often developed as part of European projects, can be complex to use or poorly suited to the needs of businesses and energy auditors. Overlap between initiatives also limits the effectiveness of the efforts undertaken.
This lack of integration of NEBs is due to methodological barriers, skills and data. The literature highlights that the absence of standardised methodologies, the lack of specific skills and the insufficiency of reliable data constitute barriers to the assessment of qualitative and quantitative NEBs. Despite progress in raising awareness and developing tools, current conclusions remain similar to those established before the European projects, reinforcing the need to train experts and harmonise assessment approaches.

INTRODUCTION

Our study presents a bibliography on NEBs methodologies, supplemented by the practical application of the European MBENEFITS method to two case studies, as well as lessons learned from European projects on the subject. The two case studies are COOPERL (excess heat recovery in the food industry) and Thyssenkrupp (electrification of their steel surface treatment). The report will be published in October, we can update our submission at that time.

FORMATTING

The manuscript must be written in English. The abstract title should be written in Arial, 12 points, and maximum of 100 characters including spaces. The section headings should be numbered, in Arial 11 pt bold.
The standard font for the manuscript is Times New Roman for the text and Symbol for special characters. Body text should be justified as block, 11 pt, in single column format.
The paper size is A4 (210 mm x 297 mm). Margins are 20 mm top, 18 mm left and right and 10 mm bottom. Do not insert a page number! References should be made exactly as shown in the example given below.
Number the sections and sub-sections.

TABLES

Table 1: Text Times New Roman 10

Graphics	Tables
Graphics	Tables

EQUATIONS

$$h_N = \sum_{i=1}^{m} C_i h_{I,i}$$

Equations should be arranged to the left and should be numbered (eq. 1)

FIGURES

Figures should be with a resolution of minimum 300 dots per inch and followed by a figure caption.

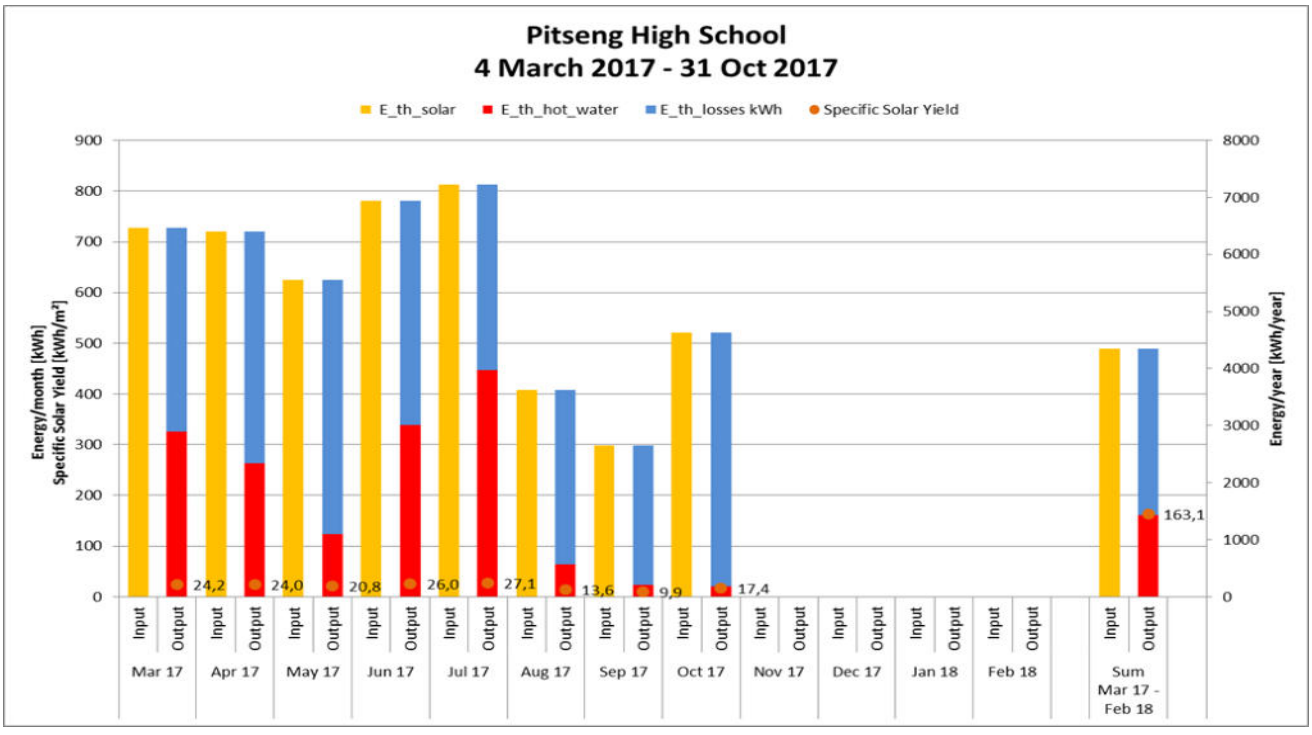


Fig. 1: Table captions (10 pt) should be justified as block and placed below the table

REFERENCES

Green, C., (2018), Heating Systems for Houses, A Design Handbook. James & James (Sience Publishers) Ltd., London, UK.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

ELENA STYRIA – A CONTRIBUTION TO THE CLIMATE-NEUTRAL FEDERAL ADMINISTRATION OF STYRIA: REVIEW AND OUTLOOK

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SUMMARY

In the "ELENA StyriA" project, the province of Styria, LIG, and the city of Graz are implementing a €52.9 million investment program under the consortium leadership of the Energie Agentur Steiermark. This includes comprehensive renewable energy measures in public buildings, the installation of building-integrated PV systems, and a switch away from gas as an energy source. Objectives: Reduction of GHG emissions and energy consumption in accordance with economic considerations.

INTRODUCTION

The European Investment Bank's (EIB) ELENA funding program supports organizations in launching large-scale investments in energy efficiency and renewable energy.
In the "ELENA Styria" project, the project partners, the Province of Styria, LIG, and the City of Graz, are currently preparing and implementing an investment program worth €52.9 million under the consortium leadership of the Energy Agency Styria. This is the first ELENA project for public buildings to be carried out in Austria.
The EIB is providing €2.6 million in financing for 90% of the costs of project development and preparation for project implementation. This will primarily be used to draw up and carry out technical plans and expert reports, technical and economic comparisons of different options, LCCAs, consultations with authorities, decision-making documents, and implementation recommendations for the individual investment projects.

ELENA is thus enabling a paradigm shift in several ways:

- Project evaluations are carried out in a cost- and resource-efficient manner before any investment decisions are made.
- Investment decisions are made on the basis of detailed figures and facts, and different implementation options are compared with each other
- Greater planning reliability and reduced cost risk for projects and programs thanks to detailed preliminary investigations

A total of €52.9 million is being invested under ELENA StyriA. This is divided into the following categories: €24.4 million for thermal renovation, €11.6 million for HVAC measures (much of which involves switching from fossil fuels to renewable energy sources or district heating), €1.5 million for lighting replacement, €14.9 million for the construction of building-integrated PV systems, and €500,000 for the installation of charging stations for electric vehicles. In total, there are approximately 175 individual projects of varying sizes, which justifies the designation "implementation program."
It could be demonstrated how, with the help of ELENA, an implementation roadmap can first be developed from many project ideas and renovation requirements according to technical, economic, and emission criteria, and how

each individual project can then be optimized according to the defined criteria. The funding of a significant portion of the planning costs is another key motivation for engaging in an ELENA project.
ELENA StyriA will already be completed by the time of the event. This means that extensive lessons learned and best practice examples can already be shared.
Further different application possibilities and constellations of ELENA projects are possible, each with individual strengths, weaknesses, opportunities, and risks that have been evaluated.

SELECTED FLAGSHIP PROJECTS WITHIN THE FRAMEWORK OF ELENA STYRIA:

Serial thermal renovation LBS + LLH Knittelfeld

- Investment: 13 million euros
- Savings: 200 tons of CO2 equivalents/year or 1,048 MWh/year

Insulation in listed buildings and replacement of lighting at Graz Castle (Grazer Burg)

- Investment in insulation: 430,000 euros
- Investment in replacement of lighting: 1.3 million euros
- Savings: 100 tons of CO2 equivalents/year or 380 MWh/year

528 kWp PV system at the Hartberg road maintenance depot (Straßenerhaltungsdienst STED)

- Investment: 1.5 million euros
- Savings: 119 tons of CO2 equivalents/year or 589 MWh/year

CONFERENCE TOPIC

Main reference to topic:

- Marketing, dissemination and implementation strategies

Also referring to topics:

- Sustainable Renovation and Energy Retrofits
- Policy Frameworks and Support Mechanisms for Renewable Heating and Cooling

REGULATION'S ROLE SHAPING PREFABRICATION FOR ENERGY RETROFIT

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SUMMARY

Renovations are central to the EU's strategy for energy efficiency and climate goals, yet deep renovation rates remain low. Prefabrication offers advantages such as speed, cost reduction, quality, and support for circular practices, but its adoption is limited by building diversity and regulatory complexity. The Horizon Europe project *DigiFab* (Grant Agreement No. 101192047) aims to create a Digital Process Chain for Energy Renovations Using Prefabrication. A review of EU, national and regional regulations shows that prefabrication helps meet performance standards but struggles with fragmented legislative frameworks. Regional rules, while reflecting local conditions, complicate standardisation. Digital workflows can address these challenges by enabling adaptability and ensuring compliance with regulatory requirements throughout the whole lifecycle of the project.
Keywords: Prefabrication, Energy retrofit, Regulatory review, barriers, enablers, EPBD, Renovation Wave.

INTRODUCTION AND AIM OF THE STUDY

Renovations have emerged as a critical pillar in the European Union's strategy to conserve energy and meet its ambitious climate targets set by the European Green Deal. As highlighted in the EU's Renovation Wave initiative, large-scale building upgrades are essential for achieving the successful decarbonisation of the European building sector—yet deep renovations that reduce energy consumption by at least 60% currently take place in only 0.2% of the building stock annually (European Commission, 2020). To accelerate this rate, policy interventions play a central role, not only facilitating the application of energy improvement technologies, but also embedding measures that safeguard user safety and wellbeing.

Prefabrication, on the other hand, has been suggested as a suitable method to achieve a systematic approach for large-scale retrofitting to improve energy efficiency. Authors highlight several advantages, including shorter execution time and lower costs, minimal disturbance to occupants, higher quality and envelope performance, integration of plug-and-play HVAC and ICT systems, and support for Circular Economy practices (Veld, 2015, D'Oca et al., 2018, Beneito et al., 2025). However, prefabricated systems are not always compatible with all building types and sites, limiting their widespread use in building renovation. Digitalisation can help to overcome this limitation by improving efficiency and facilitating the adaptation of prefabricated solutions according to specific site and building conditions, making the approach more attractive for the construction sector. The Horizon Europe project *DigiFab* specifically aims to develop a Digital Process Chain for Energy Renovations Using Prefabrication. As a first step, regulation was examined to gain a clearer understanding on the specific requirements that renovation projects have to meet, and to assess whether current frameworks facilitate or hinder the use of prefabrication in energy retrofit.

METHODOLOGY

The study primarily relied on documentary research, analytically collecting, reviewing, and interpreting regulatory documents and guiding standards at both EU level and from the *DigiFab* consortium countries, focusing on building renovation and envelope performance. These documents were analysed for scope and key legal requirements and categorised thematically using a framework based on Level(s). In parallel, a systematic

state of the art review on industrialisation in retrofitting was conducted. This review identified challenges and opportunities in implementing industrialisation and matched them with the objectives and requirements set by regulation.
The study also examined the specific regulatory requirements of the three *DigiFab* demo sites: Bruck an der Mur (Austria), Thessaloniki (Greece) and Burgos (Spain) to analyse the challenges posed by different legislative frameworks and to identify enablers, most of which are linked to the integration of digital process chains.

MAIN RESULTS AND CONCLUSIONS

The review of EU, national and regional regulations confirmed that prefabricated solutions can facilitate regulatory compliance, both in terms of construction process requirements, such as restrictions on noise or air pollution, and performance thresholds, e.g. airtightness and overall envelope performance. However, the complex legislative structure requires adaptable solutions, which often conflict with the systematic approach of prefabrication.
At the macro level, the EU either defines binding requirements through regulations and decisions or sets overarching goals through directives, which Member States then transpose into national legislation.
Further analysis of consortium countries revealed that competences for transposing EU Directives are allocated either nationally or regionally, depending on the aspect subject to regulation. Consequently, some requirements apply only within specific regions. While this allows regulation to reflect local conditions such as climate or other region-specific factors, it complicates the large-scale implementation of prefabricated solutions, which rely on standardisation.
An example of this challenge lays in the transposition of the revised Energy Performance of Buildings Directive (EU) 2024/1275 (EPBD) (European Commission, 2024a). Member States are now adapting renovation targets and setting minimum performance thresholds according to their building stock and climatic zones. Similarly, the New European Bauhaus initiative (European Commission, 2021) emphasises preserving the “sense of place” by considering local aesthetics and construction traditions. In both these cases, regulation does not create barriers but requires adaptation to local contexts and development of tailored solutions, where digital process chains can play a key role.
Promoting renovation interventions for smart buildings and digital friendly renovations is part of the Renovation Wave Strategy, which has triggered revisions of EU regulations to include digitalisation requirements. So far, these appear mainly as individual measures—such as the Construction Products Regulation (EU) 2024/3110 (CPR)) (European Commission, 2024b) requiring Digital Product Passports or the EPBD requirement for smart systems to monitor indoor air quality. The integration of a holistic digital workflow can help overcome the current challenges derived from the compliance with fragmented regulation frameworks. Digital process chains allow to evaluate multiple parameters at an early design stage helping to develop the adaptability in prefabrication methods that is required for renovation projects while complying with specific regulatory requirements. They also act as an enabling solution by allowing the integrations of multiple systems under a single solution and helping to streamline its implementation and performance monitoring throughout the project lifecycle.
Regulatory barriers were also identified as a result of the analysis. An example of these barriers is the regulation concerning the management of Construction and Demolition Waste. While prefabrication could drive Circular Economy practices, the inconsistent regional definitions of end-of-waste status and rules for the use of reused and recycled materials hinder the creation of national secondary markets needed for circular prefabricated solutions. In this case, although lack of coordination needs to be solved at a legislative level, based on preaudits and monitoring of waste generated on site, digital chains could help in the coordination of waste management with local available haulers to their integration in secondary material markets for future incorporation in other renovation projects.

REFERENCES

Beneito, L., Konstantinou, T., Torres-Ramo, J., & Sánchez-Ostiz, A. (2025), Towards decarbonisation in the built environment: a comparative analysis of conventional vs. industrialised façades in nearly zero-energy building renovations. Energy and Buildings, 342, 115885. https://doi.org/10.1016/j.enbuild.2025.115885

D'Oca, S., Ferrante, A., Ferrer, C., Pernetti, R., Gralka, A., Sebastian, R., & Veld, P. op t. (2018), Technical, financial, and social barriers and challenges in deep building renovation: Integration of lessons learned from the H2020 cluster projects. Buildings, 8(12). https://doi.org/10.3390/buildings8120174

European Commission, (2020), A Renovation Wave for Europe - Greening Our Buildings, Creating Jobs, Improving Lives. Official Journal of the European Union, Brussels, Belgium.

European Commission. (2021), New European Bauhaus Compass A guiding framework for decision and project makers wishing to apply the NEB principles and criteria to their activities. https://new-european-bauhaus.europa.eu/tools-and-resources_en

European Commission. (2024a), DIRECTIVE (EU) 2024/1275 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 April 2024 on the energy performance of buildings. Official Journal of the European Union, Brussels, Belgium.

European Commission. (2024b). REGULATION (EU) 2024/3110 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL laying down harmonised rules for the marketing of construction products. Official Journal of the European Union, Brussels, Belgium.

Veld, P. O. 't. (2015), MORE-CONNECT: Development and Advanced Prefabrication of Innovative, Multifunctional Building Envelope Elements for Modular Retrofitting and Smart Connections. Energy Procedia, 78, 1057–1062. https://doi.org/10.1016/j.egypro.2015.11.026

CONFERENCE TOPIC

Sustainable Renovation and Energy Retrofits

PLANNING AND DESIGN OF WORLD'S LARGEST CAVERN THERMAL ENERGY STORAGE - VARANTO VECTES

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SUMMARY

This work investigates cavern thermal energy storage (CTES) as a vital technology for seasonal thermal energy storage applications (sTES). CTES enables large-scale underground storage of heat, bridging seasonal mismatches between renewable supply and demand. The Varanto demo-site of INTERSTORES project, the world's largest CTES system, will employ three rock caverns to store pressurized water at up to 140°C. Such conditions create complex thermo-mechanical challenges requiring advanced design strategies. A multiphysics simulation approach using COMSOL is developed to model thermo-hydraulic-mechanical (THM) interactions. The simulations assess heat transfer, groundwater influence, temperature stratification, and stress development in surrounding rock. Results inform optimal cavern geometry, orientation, and layout to enhance efficiency and stability. Special focus is placed on deformation zones and their impact on thermal and structural performance. The study demonstrates how simulation-driven planning reduces risks and maximizes capacity.

Keywords: Cavern thermal energy storage; large thermal energy storage; district heating; COMSOL Multiphysics; thermo-hydraulic-mechanical modelling.

INTRODUCTION

As the global energy transition accelerates, large-scale seasonal thermal energy storage systems are becoming critical components of future sustainable and resilient district heating networks. Among various storage technologies, cavern thermal energy storage (CTES) offers a promising solution by enabling the storage of vast quantities of thermal energy underground with minimal land footprint. CTES systems can effectively bridge the temporal gap between renewable energy supply and heat demand, thereby enhancing the flexibility and efficiency of district heating systems and supporting decarbonization goals. Moreover, CTES systems can optimize the operation of combined heat and power with water incineration plants as they produce heat year-round including summer when heating demand is at lowest. Thus, CTES systems emerge as a crucial component for energy transition.

However, the planning and layout of CTES systems present substantial engineering challenges, particularly because they are large-scale, underground caverns. A reliable system design must consider the complex interactions between the stored thermal energy and the surrounding host rock. These interactions not only affect thermal performance but also influence mechanical stability, especially when storing pressurized hot water at high temperatures (i.e. thermal stresses).

METHODOLOGY

This work presents a simulation-driven planning and layout approach for the world's largest CTES system – Varanto, which will be realized within three adjacent rock caverns. The system is designed to store pressurized water at temperatures of up to 140°C, which introduces significant thermo-mechanical stress conditions and the

potential for deformation in fault and fracture zones in vicinity of the caverns. Consequently, a robust and integrated simulation methodology is essential for ensuring both maximum storage efficiency and long-term structural integrity.

To address these challenges, we developed a comprehensive thermo-hydraulic-mechanical (THM) model using COMSOL Multiphysics®. The model simulates key performance aspects such as charging/discharging channels, temperature stratification, heat losses to the surrounding ground, groundwater interactions, and future stress development within the rock mass. The simulation results were used to inform and optimize the geometrical configuration of the caverns, including their spatial arrangement and orientation to maximize storage capacity while minimizing thermal losses and maintaining rock stability.

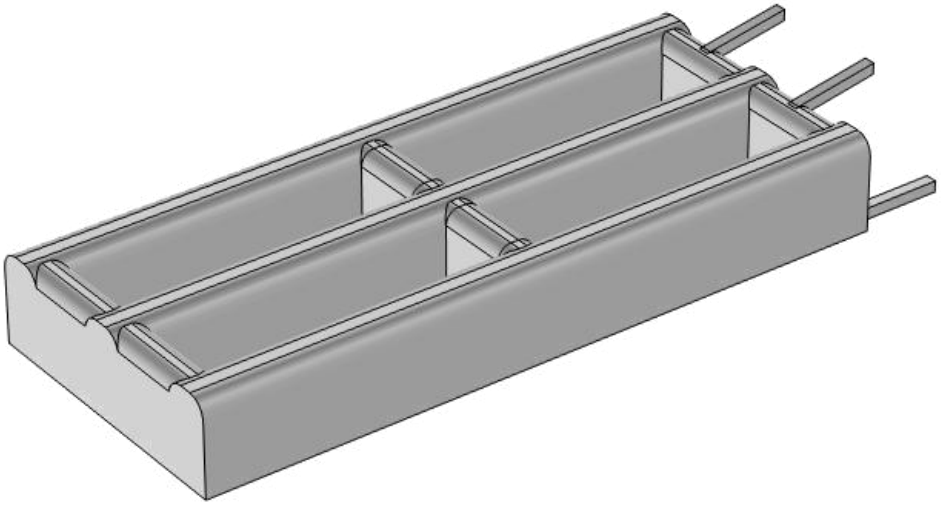
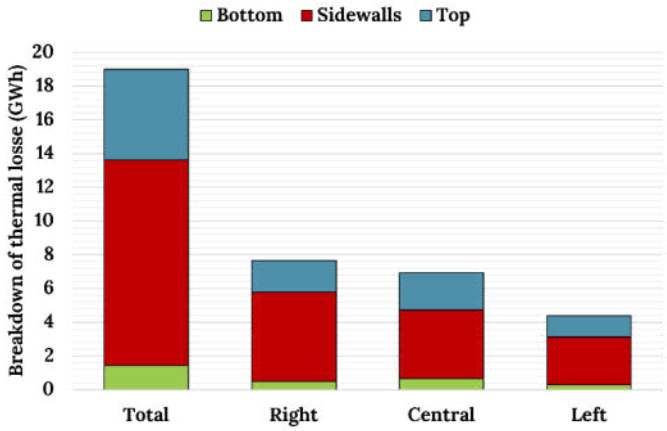


Figure 15: Initial planning and design of VARANTO VECTES.

RESULTS

Figure 16 reports recent simulation results that are directly integrated into the design and planning phase of the CTES project. These include evaluations of thermal losses, breakdown of thermal losses and VARANTO efficiency with the initial design. Besides, other simulation results showed temperature fields over time and, therefore, the design of VARANTO was modified as shown in Figure 17.



VECTES		
Storage capacity	57.5	GWh
Total thermal losses	19	GWh
Useful storage capacity	38.5	GWh
Storage efficiency	67	%
Breakdown of thermal losses		
Top	5.4	GWh
Sidewalls	12.17	GWh
Bottom	1.43	GWh
Share of thermal losses		
Right	7.65	GWh
Central	6.93	GWh
Left	4.42	GWh

Figure 16: Simulation results for planning of VARANTO VECTES.

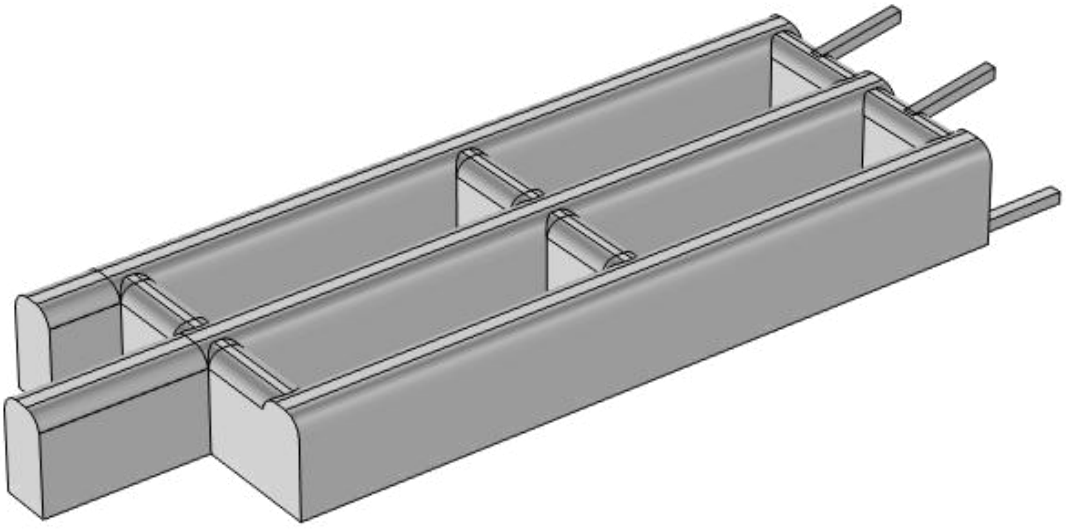


Figure 17: New design and planning of VARANTO VECTES following simulation results.

Future work will present induced mechanical stresses across different lithological units and geological structures. Special attention is given to modeling deformation zones and assessing their impact on both heat transfer and structural reliability.

In summary, this contribution demonstrates how multiphysics modeling plays a central role in the realization of next-generation underground thermal energy storage, offering key insights into performance optimization and risk mitigation. The approaches developed in INTERSTORES project are not only critical for the current CTES system but also provide a transferable framework for future large-scale energy storage solutions worldwide.

CONFERENCE TOPIC

1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage
1.08. Future District Heating and Cooling Solutions
1.04. Coupling of Energy Sectors

ENHANCED CONTROLLABILITY OF LATENT THERMAL ENERGY STORAGE IN FLEXIBEL COOLING SYSTEMS

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SUMMARY

Latent Thermal Energy Storage (LTES) utilizing phase change materials can serve as an asset for flexible cold supply for buildings as well as for industry. To increase the operation flexibility of chillers for room cooling via water to air heat exchangers, cold storage prototypes using salt hydrates and paraffin as phase change material were developed, tested and their suitability for server room cooling was elucidated. The measured energy storage density was 5-times higher in comparison to water tanks. Flexible LTES for markets access of heating and cooling systems is currently investigated. The main objective of the project is to optimize LTES by enhancing their controllability. A 150-kWh latent thermal energy storage for safer and flexible server room cooling is planned. Besides demonstration and learning from practice, the project further develops three main technologies: State-of-charge (SoC) determination technique, thermal power controller and model predictive control. SoC detection, i.e., a determination of the remaining capacity available in thermal energy storage, is crucial for optimized storage operation schedulers.

Keywords: Dold storage, phase change materials, flexible cooling, charge determination, data center.

INTRODUCTION

Data centres - technical space that include computer systems and network infrastructure for data collection, storage, or telecommunication purposes - consume energy at almost constant rates. With the increasing reliance on solar and wind electricity via chiller, the demand for effective and compact energy storage solutions has become imperative. The International Energy Agency has estimated that data centres used between 220 and 320 TWh of electricity in 2021, i.e., 0.9% –1.3% of the global final electricity demand 2018 (IEA, 2023). From 2010-2020 data center workloads rose approximately 10-fold, but energy use remained almost stable (IEA, 2022), thanks to energy efficiency improvements of equipment. Geographic clusters of data centres are established in locations with favorable conditions in terms of climate and electric supply quality.

The main advantage of phase change materials (PCMs) is the high storage density in small temperature intervals. Ice water storage tanks have been efficiently applied as constant low-temperature heat source (0 °C) in heat pump systems, leading to a higher performance for building applications (IEA SHC, 2015). To increase the flexibility of chillers operating above 8 °C – for room cooling via water to air heat exchanger – utilization of PCM with melting temperatures of 12–18 °C is aimed.

STATE OF CHARGE DETERMINATION

The State of charge of electrical batteries can be reliably detected via voltage or current measurements. For LTES, however, charge determination is based on heat flux or temperature measurements, which have several shortcomings. From a control perspective, the ideal sensor measures instantaneously, not single points and is applicable for LTES with volumes of a few liters to hundreds of cubic meters. Thus, new methods to instantaneously determine the State of charge for the bulk PCM in a LTES based on acoustic methods are currently tested.

Fig. 1 shows the prototype which has been built in accordance with the application requirements. The storage was first filled up with 230 liter of water (determination of PCM volume) and then with 304 kg of salt hydrate

composite with an onset melting temperature of 15 °C. Afterwards, it was tested with 170 kg of paraffin with an melting temperature of 18 °C.

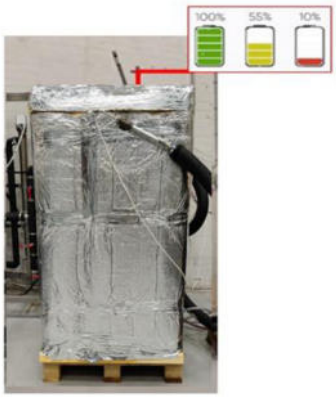


Fig. 1: Developed cold storage prototype with symbolic indication for state of charge determination

PLANNED PILOT FOR FLEXIBLE SERVER ROOM COOLING

Flexible LTES for markets access of heating and cooling systems is currently investigated in the clean energy transition partnership “La-Flex”. The main objective of the project is to optimize LTES by enhancing their controllability. Implementing a full-scale LTES unit into systems with variable demands and heat/cold production with varying cost will demonstrate how thermal energy storage reduces costs through flexibility. Monitoring and controlling the full-scale demonstration in relevant environment will provide essential operational data to better operate LTES units in terms of charge and discharge power and characteristics.

In fall 2025, a 150 kWh pilot cold storage will be implemented in existing cooling infrastructure of a server room. As shown in the schematic Fig. 2., the operation behavior regarding optimized operation of electric chillers (using predictive controls – market scheduler) as well as maximal usage of free cooling via dry cooling towers will be investigated. This installation will be realized by the following project partners: DTU Construct, Campus Service, AI-Energy (Denmark) as well as Cartesian and Sintef Energy (Norway).

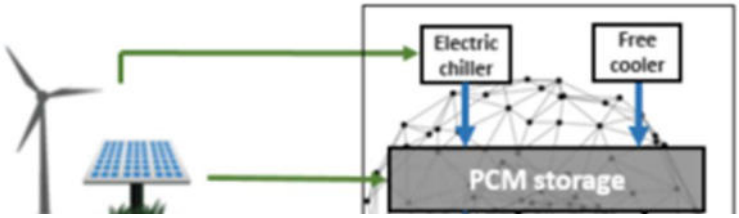


Fig. 2: Schematic overview of system investigation – PCM storage will serve for more flexible operation of electric chillers and to maximize free cooling.

With the gained data, a digital twin of the cooling system will be generated. The knowledge gathered from pilot testing will be used by industrial project partners to develop products – LTES and system controller.

REFERENCES

International Energy Agency (2023). Data centres and data transmission networks. International Energy Agency.

International Energy Agency (2022). Global trends in internet traffic, data centres workloads and data centre energy use, 2010-2020. https://www.iea.org/data-and-statistics/charts/global-trends-in-internet-traffic-data-centres-workloads-and-data-centre-energy-use-2010-2020.

IEA Solar Heating and Cooling Programme (SHC) Task 42 (2015), Compact Thermal Energy Storage, Position paper. Available: http://task42.iea-shc.org/publications

CONFERENCE TOPIC:

Emerging Heat and Cold Storage

HIGH-TEMPERATURE ATES IN FÜRSTENFELD (AUSTRIA): EARLY FINDINGS FROM THE ATESREF PROJECT

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SUMMARY

Aquifer Thermal Energy Storage (ATES) enables seasonal shifting of renewable heat by storing hot water in deep aquifers during summer and recovering it in winter. ATESref investigates the feasibility of Austria's first high-temperature ATES (HT-ATES) in the Styrian Basin near Fürstenfeld. Based on reprocessed seismic sections, borehole logs and system studies, the Sarmatian Carinthian Gravel at ≈560–650 m depth as a promising storage horizon (composite gravel thickness ≈85 m) with high permeability and good vertical confinement was identified. A coupled 3-D flow-and-heat model (implemented with FEFLOW) simulates cyclic operation (≈100 °C injection, 30 L s^{-1}), indicating thermal stability without short-circuiting after 25 cycles, a limited hydraulic influence radius (≈1.5 km), and outlet temperatures of ≈85 °C in long-term operation.

Keywords: Aquifer Thermal Energy Storage; High-Temperature Storage; District Heating; Sequence Stratigraphy; Numerical Modelling; Reinjection

INTRODUCTION

Seasonal Thermal Energy Storage (TES) is pivotal for decarbonizing heat supply by matching variable renewables to winter demand. Among UTES options, ATES is a mature and scalable solution; its high-temperature variant (≈40–90 °C and beyond, depending on site conditions) can markedly reduce fossil peak coverage when the geological conditions are favourable. In Austria, no ATES plants are currently in operation. ATESref targets the Fürstenfeld area to demonstrate HT-ATES feasibility, combining geology, hydraulics, thermal performance and energy-system integration with the local district heating grid.

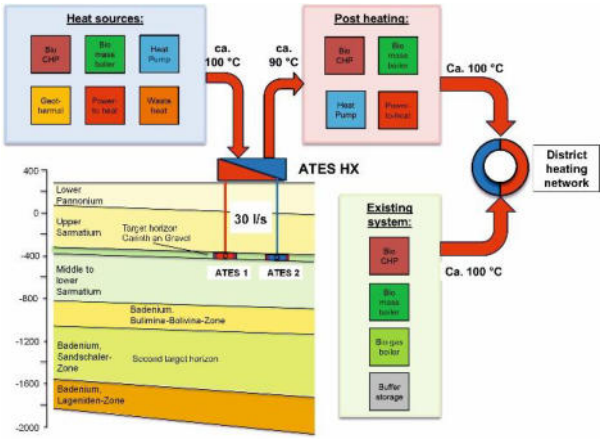


FIGURE 18: INTEGRATION OF A HIGH-TEMPERATURE ATES INTO THE FÜRSTENFELD DISTRICT HEATING SYSTEM.

METHODOLOGY

Energy system characterization. Demand profiles and the current heat mix of Fürstenfeld's district heating were analysed, potential surplus summer heat sources (biomass CHP/boilers, industrial waste heat, heat pumps, power-to-heat) were mapped, and 2030 scenarios were used to quantify charging potential and winter post-heating requirements.

Geological & hydrogeological framework. Ten deep wells in the Styrian Basin (e.g., Fürstenfeld FF1/FF2, Frutura, Ilz, Loipersdorf, Blumau, Übersbach) constrain the Carinthian Gravel at ≈560–650 m depth; stacked gravel beds (≈1–10 m) sum to ~85 m of total thickness between clayey aquitards that provide also an effective vertical confinement. Pumping-test reinterpretations indicate kf ≈ 10^{-5}–10^{-6} m s^{-1} and transmissivity T ≈ 10^{-4} m^2 s^{-1}, sufficient for target flow rates if clogging is controlled.

Sequence stratigraphy & seismic. Reprocessed 2-D seismic and stratigraphic markers (Sarmatian/Pannonian) indicate lateral continuity of the reservoir and no major fault barriers at the site, supporting single-reservoir behaviour and scalability to multiple doublets.

Numerical simulations. A 3-D FEFLOW model with confining clay/marl layers, regional gradient and heat flux simulates annual cycles: charge (mid-May–mid-Sep) at ≈100 °C / with 30 L s^{-1}, discharge (mid-Nov–mid-Mar), and holding phases, over 25 years. Sensitivities cover well spacing, operation schedules and thermal/hydraulic parameters.

RESULTS

Integration concept. A diversified charging portfolio and post-heating (biomass, heat pumps, electric boilers) can deliver ≈100 °C to the grid while maximising renewable utilisation; techno-economic optimisation is in progress.

Hydrogeology & injectivity. The target aquifer shows favourable permeability and confinement; however, regional experience (1999 tests at FF1/FF2) revealed injectivity decline from fines/clogging. Measures prioritised include filtration, periodic backwash, maintaining positive pressure to avoid gas exsolution, and adapted screen/chemistry management to sustain ≈30 L s^{-1} per well at moderate overpressure.

Thermal-hydraulic behaviour. Simulations show (i) no thermal short-circuiting after 25 cycles; (ii) outlet temperatures ~85 °C after long-term operation; (iii) limited heat-plume advection under the regional gradient (≈3‰, NWW→SEE); and (iv) a hydraulic influence radius ~1.5 km during alternating extraction/injection. Neighbouring wells remain unaffected.

DISCUSSION AND OUTLOOK

The Carinthian Gravel at Fürstenfeld offers a thick, laterally continuous, high-k_f reservoir with strong aquitard confinement—conditions well suited for HT-ATES. The dominant risk is sustained reinjection in a clastic system. Targeted operational controls and well designs (filtration; backwash/chemical maintenance; potential multi-well distribution of hydraulic/thermal load) are expected to mitigate decline. At system level, integrating ATES with heat pumps, biomass and existing geothermal heat can significantly displace gas in winter; the optimal operation strategy concerning the charging and discharging of the ATES will depend on electricity prices and emission factors and will be resolved by the ongoing techno-economic assessment.

CONCLUSION

ATESref lays the groundwork for Austria's first HT-ATES: geology, hydraulics and modelling indicate technical feasibility and meaningful CO_2 reductions by shifting summer renewable heat to winter. Next steps include validating injectivity controls, calibrating models with new measurements, and finalising the integration and business case for implementation in Fürstenfeld's district heating and/or large heat consumers.

REFERENCES

Bloemendal, M., & Hartog, N. (2018). Impact of storage conditions on HT-ATES. *Geothermics, 71*, 306–319.

Cabeza, L. F., Martorell, I., Miró, L., Fernández, A. I., & Barreneche, C. (2015). Introduction to TES systems. In *Advances in Thermal Energy Storage Systems*. 1-28, Elsevier.

Diersch, H.-J. G. (2014). *FEFLOW – Flow, Mass and Heat Transport in Porous/Fractured Media*. Springer.

Fleuchaus, P., Gotschalk, B., Stober, I., & Blum, P. (2018). Worldwide ATES – Review. *Renewable and Sustainable Energy Reviews, 94*, 861–876.

Schreilechner, M., & Sachsenhofer, R. (2007). Sequence stratigraphy in the Eastern Styrian Basin. *Austrian Journal of Earth Sciences*, *100*, 164-184.

IEA (2020). *Energy Technology Perspectives 2020*. International Energy Agency.

CONFERENCE TOPIC

Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications — *Emerging Heat and Cold Storage*

CHARACTERIZATION OF A LARGE LAB-SCALE LATENT HEAT STORAGE

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SUMMARY

According to the 2nd law of thermodynamics, a driving temperature difference is always required for the transfer of heat resulting in a higher charging than discharging temperature of thermal energy storages. By using latent heat thermal energy storage (LH-TES), the driving temperature difference between charging and discharging can be minimized, resulting in higher exergetic efficiency. A dual-tube LH-TES concept was developed and tested with an organic Rankine cycle and a high temperature heat pump, as discussed at the ISEC in 2024. Thereafter, testing in an extended parameter range of temperatures and mass flow rates was conducted in order to allow for an in-depth characterization of the system. The results show that the LH-TES with a nominal melting temperature of 133 °C is capable of storing up to 124 kWh of heat in a temperature range of 104 to 139 °C with a maximum heat flow rate of up to 90 kW. Data from the experimental analysis will be shown and discussed.

INTRODUCTION

The LH-TES tested here was designed for the coupling of a high-temperature heat pump and an organic Rankine cycle in order to create a flexible energy management system, as discussed in [1]. The heat pump upgrades heat, thereby evaporating the refrigerant. This condenses in the LH-TES, thereby charging the storage. When energy is dispatched again, the other refrigerant is pumped through the LH-TES, evaporating and discharging it. This is then condensed in the organic Rankine cycle while converting a portion of the thermal energy to electricity. The coupling of these systems required not only the driving temperature difference between the charging and discharging cycles in the LH-TES, but also differing refrigerants as well as lubricants for the heat pump and organic Rankine cycle machines. To this end, this storage concept was developed, built and tested, as discussed in [1].

The LH-TES unit is designed as a vertical shell and tube heat exchanger whose shell is filled with phase change material (PCM) consisting of a nitrate salts mixture. This allows for condensation and evaporation of the working fluids in the tubes at small temperature differences with respect to the melting temperature of the PCM on the shell side in order to minimize entropy generation in the system. Hence the exergetic heat transfer efficiency between the PCM and working fluid is maximized.

Axial aluminum fins connect the two tube systems and are immersed in the PCM storage media. These improve the heat transfer between the PCM and the working fluid in the heat exchanger tubes, since nitrate salts generally have a low thermal conductivity of about 0.5 W/m/K [1]. In the desired temperature range, aluminum is a suitable fin material due to its high thermal conductivity (210 W/m/K) and formability. Figure 19 shows a dual tube assembly consisting of two fin segments and two steel tubes on the left and the storage integrated into the lab in the middle. Figure 19 on the right shows the heat transferred out of the storage unit during discharging at different mass flow rates. In addition to the mass flow rate variations, variations in operating temperatures for the refrigerant were analyzed.

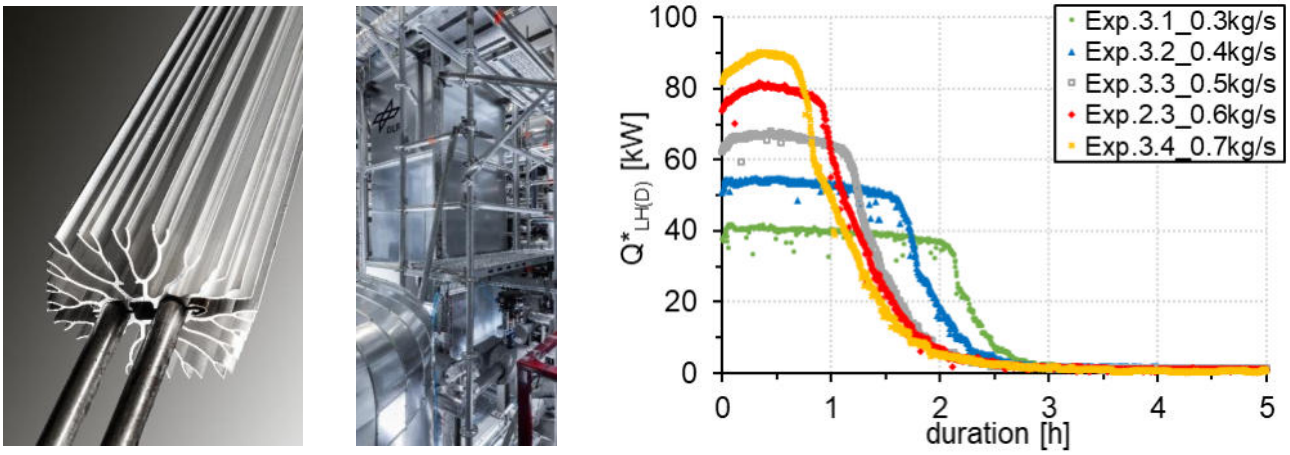


Figure 19: Dual tube assembly (left) and latent heat storage integrated into the lab (middle) and variation in heat flow rate with variation in mass flow rate [3] (right).

CONCLUSIONS

The storage characterization was conducted by an extensive testing and variation in mass flow rate and temperatures using one tube set of a dual-tube storage unit. A eutectic KNO_3-$LiNO_3$ mixture with a phase change temperature of about 133 °C is the PCM and R1233zd(E) the heat transfer fluid. The results show good heat conduction into the storage unit. No significant improvement in the results is expected by using both instead of one of the tube systems.

The storage unit discharging was characterised by a variation in mass flow rates between 0.3 kg/s and 0.7 kg/s, indicating that mass flow rate control is well suited for adjusting the vapour superheating and maximum heat flow rate. A variation in evaporation temperature between 109 °C and 129 °C showed an optimum at 114 °C for maximizing the latent heat plateau length, which is strongly influenced by the PCM.

The PCM selected and analysed in this study was determined by constrictions in the system setup in [1]. A more economical PCM with a higher phase change temperature for process steam generation would increase overall feasibility, whereby this depends strongly on the heat source temperatures for the integration process.

REFERENCES

[1] Theologou, K., Johnson, M., Tombrink, J., Ciganda, J., Trebilcock, F., Couvreur, K., Tassenoy, R. and Lecompte, S. (2024) CHESTER: Experimental prototype of a compressed heat energy storage and management system for energy from renewable sources. Energy Conversion and Management, 311 (118519), ISSN 0196-8904. doi: 10.1016/j.enconman.2024.118519.

[2] Mehling H., Cabeza L. F., *Heat and cold storage with PCM*, Springer, 2008.

[3] Theologou, K., Dietz, L., Tombrink, J. and Johnson, M. (2025) Experimental characterization of a vertical shell-and-tube latent heat thermal energy storage with dual-tube finned tubes for evaporation at temperatures about 133 ◦C. Journal of Energy Storage, 133 (117841). ISSN 2352-152X. doi: 10.1016/j.est.2025.117841.

CONFERENCE TOPIC

1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

"SCALEUP"- SEASONAL UNDERGROUND THERMAL ENERGY STORAGE AS A KEY TECHNOLOGY FOR CLIMATE-NEUTRAL DISTRICT HEATING IN VIENNA

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SUMMARY

To achieve climate neutrality in Vienna by 2040, a fundamental transformation of the city's heating infrastructure is required. District heating must cover approximately 56% of Vienna's total heating demand, making it a cornerstone of the city's energy transition. One of the key technologies enabling this shift is **seasonal underground thermal energy storage (UTES)**, which allows surplus renewable heat to be stored during warmer months and retrieved during colder periods, thereby balancing supply and demand efficiently.

The **EU-funded ScaleUp pilot plant**, with a planned capacity of 40,000 m³, will be constructed at the **Donaustadt power plant site operated by Wien Energie** and serve as a demonstration facility for integrating UTES into Vienna's district heating network. The project encompasses a wide range of activities, including **system simulations**, **environmental monitoring**, and **economic and ecological evaluations**, all aimed at validating the feasibility and scalability of UTES in urban environments.

By combining innovative insulation materials, advanced structural designs, and a multifunctional surface concept, the pilot plant seeks to preserve urban space while contributing to the decarbonisation of the heating sector. The insights gained will lay the groundwork for future large-scale storage systems and support Vienna's long-term strategy for a sustainable, resilient, and fossil-free energy future.

Keywords: district heating, seasonal storage, geothermal energy, urban energy systems, climate neutrality, thermal energy storage, energy transition.

INTRODUCTION

Vienna has committed to becoming climate-neutral by 2040. This ambitious goal requires a comprehensive shift in the city's energy systems, particularly in the heating sector, which is currently responsible for a significant share of CO_2 emissions. District heating is expected to play a central role in this transformation, with more than half of the city's heating demand to be covered by it. To achieve this, the integration of renewable energy sources and innovative technologies is essential.

Seasonal underground thermal energy storage (UTES) offers a promising solution to store excess heat from renewable sources such as solar thermal, waste heat, and geothermal energy. By enabling temporal decoupling of heat generation and consumption, UTES enhances system flexibility and supports the efficient use of renewable energy throughout the year.

PROJECT OVERVIEW

The ScaleUp project builds on a completed research initiative from 2021, which investigated the technical and environmental feasibility of UTES in urban settings. Based on these findings, a concept and preliminary study were developed for a pilot plant at the Donaustadt power plant site. The planned facility will have a storage volume of 40,000 m³ and is designed to minimize its impact on the urban landscape by allowing the surface above the storage to remain usable for other purposes, such as green spaces or infrastructure.

This multifunctional approach supports sustainable urban development and demonstrates how energy infrastructure can be harmoniously integrated into densely populated areas. The pilot plant will serve as a testbed for technical innovations, operational strategies, and environmental safeguards.

TECHNICAL AND ENVIRONMENTAL ASPECTS

To ensure the long-term efficiency and environmental compatibility of the storage system, the project investigates advanced insulation materials and optimized wall structures. These elements are crucial to prevent unwanted heat loss and to protect surrounding soil and groundwater from thermal influence. Together with research partners, simulations and laboratory tests were conducted to validate the materials and design.

A comprehensive monitoring concept is being developed to track both system performance and environmental parameters, ensuring compliance with geological and ecological standards. This includes temperature sensors, groundwater quality assessments, and soil stability analyses.

SYSTEM INTEGRATION AND ECONOMIC EVALUATION

The integration of UTES into Vienna's existing district heating network poses both technical and operational challenges. The project addresses these by simulating various scenarios of heat input and withdrawal, evaluating the dynamic interaction with other heat sources such as waste heat, solar thermal, and geothermal energy.

An economic analysis will assess the cost-effectiveness and ecological impact of UTES in comparison to other renewable technologies. This includes lifecycle assessments and portfolio simulations to determine the optimal mix of heat generators for a future-proof district heating system. The results will inform investment decisions and policy frameworks for large-scale deployment.

OUTLOOK AND UPSCALING

The pilot plant is a crucial step toward the large-scale deployment of UTES in urban areas. Insights gained during construction and operation will inform the design of future storage systems with capacities of several hundred thousand cubic meters. The ongoing FFG research project (running until 2026) supports the scaling process by refining technical concepts and validating operational models.

Ultimately, UTES is expected to become a cornerstone of Vienna's renewable heat supply, contributing significantly to the decarbonisation of urban energy systems and serving as a model for other cities aiming for climate neutrality.

CONFERENCE TOPIC

- Next-Generation Technologies for Renewable Energy and Resource Efficiency
  Renewable Heating and Cooling Solutions for Low, Medium and High Temperature
- Transform Cities: Holistic Approaches to Sustainable Urban Energy
- Industrial and Urban Symbiosis

The project's implementation is funded by the European Union under the EU Innovation Fund. The FFG research project is funded by Klima- und Energiefond.

ENABLING ENERGY EFFICIENT PROCESSING IN CIRCULAR ECONOMY VIA OSCILLATORY FLOW

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The rise of complexity of secondary raw materials makes it essential to focus on the most targeted process driving forces in order to recover valuables from these resources. In this way the application of processing engineering technologies that follow the principles of process intensification are key in circular economy concepts. On the other hand, processes must be simple and scalable in order to be deployed economically for secondary raw material processing. Oscillatory flow reactors for continuous slurry and waste water processing at high mass transfer rates, are examples of such key enabling technologies, that can help to realize targeted processes for valuable recovery under the framework of green chemistry and energy efficient processing.

This abstract brings together key results of oscillatory flow reactors for 3 applications, namely (1) hydrolysis of biobased feedstock for biorefining (glucose hydrolysis and protein extraction) as well as (2) solar photoelectrochemical reduction of waste water to hydrogen or CO2 to fuel products and (3) oscillatory flow in membrane processes.

(1) The enzymatic hydrolysis of biomass is generally a sustainable but slow process that greatly benefits from enhanced mixing and continuous processing in an oscillatory flow reactor. The respective oscillatory flow characteristics allow for process intensification to greater solid loadings and increased reaction rates: Specifically, the continuous enzymatic hydrolysis of lignocellulosic slurries in oscillatory flow has reduced residence times by 40%, reaching comparable glucose concentration levels to those in traditional batch reactors.[1,2] Similar results of intensified hydrolysis have been proven for basic extraction of proteins from thick food waste slurries. While enzymatic hydrolysis will still not be as "intense" as harsh chemical hydrolysis, this example successfully demonstrates that we can find means by process intensification to advance sustainable reaction routines and develop continuous, scalable reactors for biogenic slurry processing.[1,3] In-situ outtake of products during the enzymatic hydrolysis could be successfully demonstrated in-line of the oscillatory flow reactor further improving glucose yields by 20%.

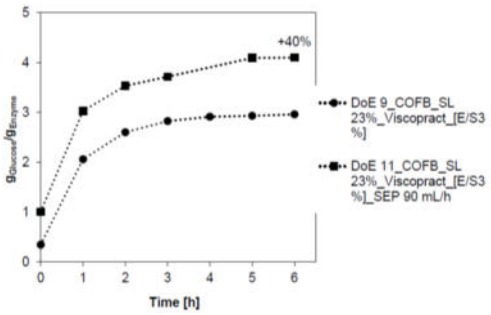


Figure 20: Effect on separation rate during enzymatic hydrolysis in a continuous oscillatory flow bioreactor[4]

(2) Likewise, PI approaches can help to intensify photo-electrochemical processes under real sunlight conditions. The development of solar reactors that integrate photochemical processes into solar collectors is an important research field, aiming for the direct utilization of solar photons in the synthesis of chemicals and fuels. While material research for photo-catalysts has been a central topic for years, the development of solar reactors for such processes on scale[5–9] – especially when combined with electrochemical conversions – is still in need of greater exploration. It is vital to understand the influence of photon and mass transfer within the reactor geometry in order to enhance photon transfer to active photocatalyst sites. In addition, practical challenges under real-sunlight include the useful wavelength ranges of the full sunlight spectrum by catalysts, the required photon intensity – which can have different optima for different catalysts - for area-efficient reactor designs and the combined photon and heat management in case parts of the solar spectra are still converted to heat. Considering PI principles to minimize transfer losses, novel solar flow reactor concepts are showing promising increases in photon-efficiencies in a broadening range of applications.[10–13] Our work demonstrates the potential of oscillatory flow to enhance solar fuel yields by factors of 1.5 to 5 in a novel single-tube continuous reactor, which lay the basis for further simulation-assisted novel designs of PEC reactors.

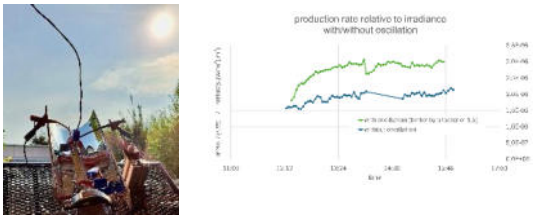


Figure 21: Solar PEC test stand (left) and Effect on hydrogen evolution rate with oscillatory flow (Meitz et al, 2025)

(3) In membrane applications in circular economy, it is often essential to process waste waters or process liquids with high solid contents. In order to mitigate fouling and maximise transmembrane fluxes, the increase of turbulences at the membrane-feedstream interface has often been studied, however usually at the expense of energy requirement due to increased recirculation rates across the membrane. Oscillatory flow membrane distillation can be one solution to reach this target in an energy efficient and process effective manner – transmembrane fluxes can be increased > 40% at low energy requirement, while reducing feed flow rates and allowing membrane applications at high presence of solids in waters.

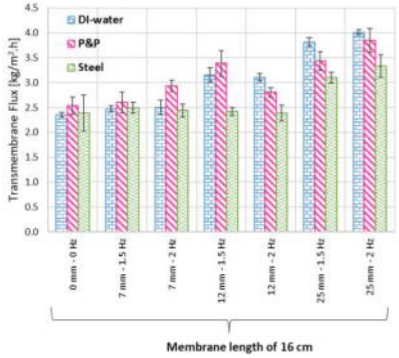


Figure 22: Increase in transmembrane flux for all tested waters (DI-water, P&P effluent and Steel effluent) and varying oscillation conditions (oscillation amplitude and frequency) for short membrane bundle (16 cm) (Pane et al, 2025)

This work analyses specifically the energy demand for oscillatory flow reactors in these various context, which ranges from 0.02-0.6 Wh/kg slurry or feed stream, in order to evaluate oscillatory flow as energy and resource efficient key enabling technology. Energy intensity is influenced by physio-chemical feed stream characteristics, oscillation intensity and reactor length.

In the circular economy context, process intensification (PI) as debottlenecking method can be extremely helpful in identifying how we can change our current processing routines towards greater energy efficiency by analyzing the core functions and underlying driving forces to achieve it. One of the objectives is to overcome process bottlenecks such as mass transfer limitations by advanced mixing or continuous processing technologies that minimize the required residence time and increase space-time yields. Specifically for this target, oscillatory flow reactors can be a key enabling technology, which will need further boost in larger scaled reactor designs for industrial exploitation.

REFERENCES

(1) Buchmaier, J.; Krampl, S.; Eibinger, M.; Kaira, G. S.; Nidetzky, B.; Muster -Slawitsch, B. Continuous Oscillatory Flow as Process Intensification Strategy in Protein Extraction from Brewer's Spent Grain. *Chemical Engineering and Processing - Process Intensification* **2024**, *200*, 109772. https://doi.org/10.1016/j.cep.2024.109772.

(2) Muster-Slawitsch, B.; Buchmaier, J.; Brunner, C.; Nidetzky, B.; Gudiminchi, R. K.; Harvey, A. P.; Phan, A. N. Oscillating Flow Bioreactors: An Enabling Technology for Sustainable Biorefining Operations? *Jnl Adv Manuf & Process* **2020**, *2* (2). https://doi.org/10.1002/amp2.10046.

(3) Wang, H.; Mustaffar, A.; Phan, A. N.; Zivkovic, V.; Reay, D.; Law, R.; Boodhoo, K. A Review of Process Intensification Applied to Solids Handling. *Chem. Eng. Process. Process Intensif.* **2017**, *118*, 78–107. https://doi.org/10.1016/j.cep.2017.04.007.

(4) Plesch, T. *Enzymatic Hydrolysis of Cellulosic Material in an Oscillatory Flow Bioreactor (OFB) at High Solid Loadings*; Master thesis; Graz University of Technology, 2025; p 100.

(5) Qureshy, A. M. M. I.; Dincer, I. A New Photoelectrochemical Reactor Designed for Solar Hydrogen Fuel Production: Experimental Study. *Chemical Engineering Science* **2022**, *250*, 117404. https://doi.org/10.1016/j.ces.2021.117404.

(6) Liu, B.; Wang, T.; Wang, S.; Zhang, G.; Zhong, D.; Yuan, T.; Dong, H.; Wu, B.; Gong, J. Back-Illuminated Photoelectrochemical Flow Cell for Efficient CO2 Reduction. *Nat Commun* **2022**, *13* (1), 7111. https://doi.org/10.1038/s41467-022-34926-x.

(7) Xing, Z.; Zong, X.; Pan, J.; Wang, L. On the Engineering Part of Solar Hydrogen Production from Water Splitting: Photoreactor Design. *Chemical Engineering Science* **2013**, *104*, 125–146. https://doi.org/10.1016/j.ces.2013.08.039.

(8) Kim, J. H.; Hansora, D.; Sharma, P.; Jang, J.-W.; Lee, J. S. Toward Practical Solar Hydrogen Production – an Artificial Photosynthetic Leaf-to-Farm Challenge. *Chem. Soc. Rev.* **2019**, *48* (7), 1908–1971. https://doi.org/10.1039/C8CS00699G.

(9) Ruiz-Aguirre, A.; Villachica-Llamosas, J. G.; Polo-López, M. I.; Cabrera-Reina, A.; Colón, G.; Peral, J.; Malato, S. Assessment of Pilot-Plant Scale Solar Photocatalytic Hydrogen Generation with Multiple Approaches: Valorization, Water Decontamination and Disinfection. *Energy* **2022**, *260*, 125199. https://doi.org/10.1016/j.energy.2022.125199.

(10) Sambiagio, C.; Noël, T. Flow Photochemistry: Shine Some Light on Those Tubes! *Trends Chem.* **2020**, *2* (2), 92–106. https://doi.org/10.1016/j.trechm.2019.09.003.

(11) Quershy, A. M. M. I.; Dincer, I. Development of a New Solar Photochemical Reactor Design for More Efficient Hydrogen Production. *Energy Convers. Manage.* **2021**, *228*, 113714. https://doi.org/10.1016/j.enconman.2020.113714.

(12) Li, P.; Kowalczyk, D.; Liessem, J.; Elnagar, M. M.; Mitoraj, D.; Beranek, R.; Ziegenbalg, D. Optimizing Reaction Conditions for the Light-Driven Hydrogen Evolution in a Loop Photoreactor. *Beilstein J. Org. Chem.* **2024**, *20* (1), 74–91. https://doi.org/10.3762/bjoc.20.9.

(13) Meitz, S. Photoelectrochemical and Photocatalytic Conversion of Wastewater to Alternative Fuels - Applying and Validating a New Solar Collector Concept, 2023.

ALUMINIUM AS AN EMERGING LONG-TERM ENERGY STORAGE VECTOR

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SUMMARY:

As part of the EU Horizon Europe project REVEAL, a 4 kW Alu-to-Energy prototype was developed and built. The prototype is part of an innovative seasonal energy storage cycle, in which aluminium oxide is reduced to aluminium at locations and times with abundant renewable electricity, while aluminium is oxidised at locations and times with limited renewable energy, thereby releasing the chemically stored energy. The oxidation reaction of aluminium with water releases heat and produces hydrogen, which can be converted into electricity in a fuel cell. This study describes the process engineering concept of the continuously operable Alu-to-Energy prototype and its quantitative validation. According to efficiency measurements, the conversion efficiency of aluminium to hydrogen is 101.5 ±10.5 % (2σ) and the heat extraction efficiency of the current prototype is 82.3 ±14.3% (2σ). The prototype reached a total reaction power of 3.6 kW and is thus close to the targeted value.
Keywords: ReMEC, MeCRE, Aluminium, seasonal energy storage, Al-water reaction, Al-to-Energy, CHP-unit

INTRODUCTION:

Today, electricity and heat can be generated from renewable energy sources at relatively low cost, and there are several cost-effective short-term storage solutions. However, technologies for the long-term storage of renewable energy remain scarce and expensive. A promising option for seasonal energy storage that is currently being researched is the aluminium-based energy storage cycle. The charging of the storage is achieved by the reduction of oxidised aluminium (Al^{3+}) to elemental aluminium (Al) in central processing plants at locations and times of high availability of renewable electricity. In places and at times with high energy demand and low availability of renewable energy, discharging takes place through aluminium oxidation.
This study describes the findings from the experimental validation of an Alu-to-Energy CHP-unit, developed and built as part of the EU Horizon Europe project REVEAL (www.reveal-storage.eu). The evaluated prototype is designed for a total output of 4 kW (2 kW_{H2} and 2 kW_{th} or 1 kW_{el} and 3 kW_{th}) and is conceptualised for continuous operation. The continuous operation is made possible through periodic and automatic mass transfer between different reaction vessels and periodic automatic removal of solid reaction products, which distinguishes the prototype from earlier developments in this field (e.g. [1], [2]). The three main components of the prototype built are the Reaction Vessel, the Crystallisation Vessel and the Sedimentation Vessel, all of which are filled with a specific amount of 2 M sodium hydroxide (NaOH) solution and are under a defined overpressure (1.5-3.9 bara). In the Reaction Vessel, the Al-water oxidation reaction takes place at a temperature of 70 °C and hydrogen (H_2) and aluminium hydroxide ($Al(OH)_3$) are formed. The reaction heat (2 kW) is extracted from the stirred solution by an internal heat exchanger and the reactants, aluminium and water, are periodically added to the vessel. To prevent accumulation of $Al(OH)_3$ in the Reaction Vessel, liquid with dissolved and solid $Al(OH)_3$ is periodically transferred to the Crystallisation Vessel where any carried over Al granules can react to completion and the crystallisation rate is kept high by stirring. At the same time intervals, liquid is transferred from the Crystallisation Vessel to the Sedimentation Vessel, where the solid $Al(OH)_3$ crystals settle to the bottom. The sediment is discharged via a valve at the bottom of the Sedimentation Vessel and the NaOH solution is pumped back into the

Reaction Vessel to close the cycle. The hydrogen produced may be fed to a water-cooled Fuel Cell Power System (FCPS), where it is converted into electrical (1 kW) and thermal (1 kW) power at nominal power conditions. To compensate for short-term fluctuations in hydrogen production, a Hydrogen Buffer Tank is used.

RESULTS

The quantitative validation of the prototype was carried out at half of the rated power, as this output allows for more stable operation at the current stage of development. Fig. 6 shows the calorific output of hydrogen produced and the heat extracted from the oxidation reaction during an experiment of 6 hours. If the measurement data in the quasi-stationary range (13:00-14.30) is used to calculate the conversion efficiencies, the resulting conversion efficiency for hydrogen production is 101.5 ±10.5 % (2σ) which is in line with small-scale measurements from the chemistry laboratory [3]. However, it became apparent that achieving a steady-state operating condition with the prototype is difficult, as it is challenging to maintain constant levels of process conditions such as NaOH molarity and aluminate concentration. The heat extraction efficiency of the oxidation reaction is 82.3 ±14.3% (2σ) at 50 % part-load conditions, which means that around 20 % of the heat is lost through dissipation to the ambient. Extrapolated to full-load conditions, this loss could possibly be reduced to 10 % if it remains constant in absolute terms whereas the energy turnover doubles at the same time. The efficiency measurements of the coupled process (Alu-to-H_2 & H_2-to-Power), which are also part of this study, are currently being carried out and will allow for a complete energy balance of the prototype.

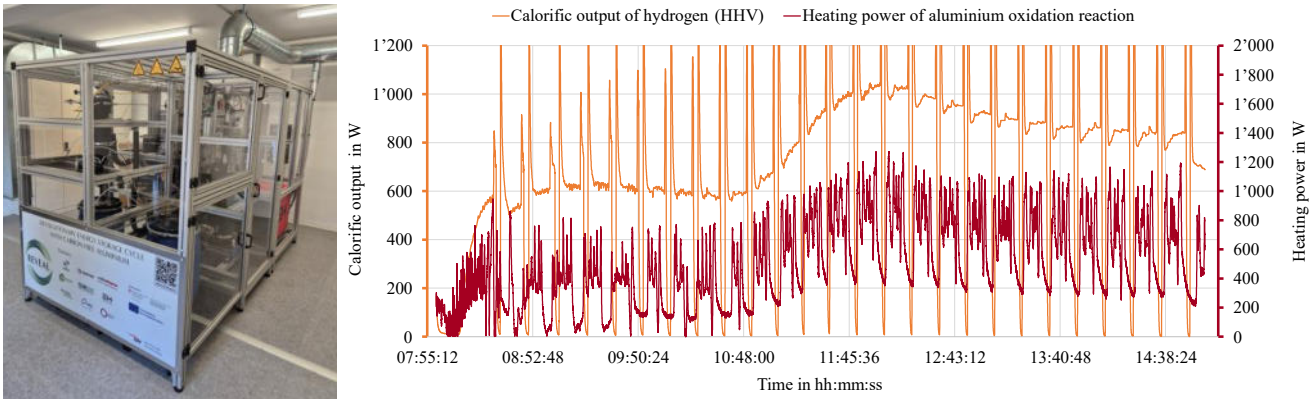


Fig. 6 left.) Photo of the 4 kW_{tot} Al-to-Energy prototype developed and built in the EU Horizon Europe project REVEAL; right.) Calorific output of hydrogen (HHV) and heating power of the oxidation reaction over time during an experiment of 6 hours. Periodic peaks and minima in the measured data are caused by the periodic volume exchange between the different reaction vessels to discharge solid $Al(OH)_3$ from the main reaction vessel.

FUNDING

The presented work contributes to the REVEAL research project co-funded by the European Union under Grant Agreement No. 101069492 and the Swiss State Secretariat for Education, Research, and Innovation (SERI).

REFERENCES

[1] M. Y. Haller, D. Amstad, M. Dudita, A. Englert, and A. Häberle, 'Combined heat and power production based on renewable aluminium-water reaction', *Renewable Energy*, vol. 174, pp. 879–893, Aug. 2021, doi: 10.1016/j.renene.2021.04.104.

[2] D. W. Hurtubise, D. A. Klosterman, and A. B. Morgan, 'Development and demonstration of a deployable apparatus for generating hydrogen from the hydrolysis of aluminum via sodium hydroxide', *International Journal of Hydrogen Energy*, vol. 43, no. 14, pp. 6777–6788, Apr. 2018, doi: 10.1016/j.ijhydene.2018.02.087.

[3] M. Agote-Arán, B. Welte, R. Freeman, N. Mutti, M. Haller, and A. Heel, ‘Al6060 cut wire granules for Al-water reaction: Evaluation of reaction conditions and granule treatments’, *International Journal of Hydrogen Energy*, vol. 117, pp. 430–441, Apr. 2025, doi: 10.1016/j.ijhydene.2025.03.117.

CONFERENCE TOPIC

Next-Generation Technologies for Renewable Energy and Resource Efficiency

PLUG & PLAY ENERGY MANAGEMENT FOR HYBRID ENERGY STORAGE INNOVATIVE CONCEPTS FOR THE OPTIMAL USE OF HYBRID ENERGY STORAGE SYSTEMS

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SUMMARY

The ongoing digitalization of the energy system enables new applications to support the energy transition, but it also leads to a fragmentation of platforms, protocols, and standards. The PARMENIDES project addresses these challenges by developing an ontology-based energy management system for the use of Hybrid Energy Storage Systems (HESS).

PARMENIDES ENERGY COMMUNITY ONTOLOGY UND ENERGIEMANAGEMENT SYSTEME

Key element of the PARMENIDES project is the PARMENIDES Energy Community Ontology (PECO), which provides a formal semantic framework for representing key concepts, relationships, and attributes within Renewable Energy Communities (RECs). PECO facilitates semantic interoperability across heterogeneous data models and system components, spanning multiple operational layers. It explicitly incorporates regulatory distinctions, particularly between the pilot countries Austria and Sweden, and encompasses domains such as energy distribution, pricing mechanisms, asset characteristics, and user preferences.

A central objective of the project is the design, deployment, and validation of a scalable and generic Energy Management System (EMS4HESS) grounded in PECO. This system supports the flexible modelling of complex multi-vector energy systems, enabling dynamic integration and optimization of diverse energy assets. Interoperability is achieved through a modular system architecture comprising connectors, semantic adapters, a central broker, and federated authentication mechanisms.

Newly integrated assets are automatically identified, classified, and incorporated into optimization workflows using PECO-based semantic reasoning—for instance, in the forecasting of renewable energy generation. The result is an intelligent, interoperable, and scalable energy management infrastructure tailored to the evolving needs of future energy communities.

PARMENIDES IN AUSTRIA – GRID-FRIENDLY COMMUNITIEIS IN THE PILOT REGIONS IN GASEN UND HEIMSCHUH

Within the framework of the PARMENIDES project, the deployment of grid-compatible energy communities is being demonstrated in the Austrian pilot regions of Gasen and Heimschuh. The Gasen pilot features a Hybrid Energy Storage System (HESS) comprising a 140 kWh battery with a charge/discharge capacity of 80 kW. The infrastructure includes both public and private 22 kW electric vehicle charging stations and involves 12 participants, including residential buildings, hospitality businesses, a public facility, and a district heating system. The total photovoltaic (PV) feed-in capacity amounts to approximately 370 kW.

Energy consumption and generation are monitored using smart meters and energyLIVE adapters with a temporal resolution of one minute. Additionally, high-resolution measurement devices (Siemens PAC) are deployed to capture voltage data at selected participant sites and at the transformer station. A machine learning-based

Distribution System State Estimation (DSSE) algorithm supplements the monitoring system by providing enhanced grid state indicators.
The Heimschuh pilot integrates a 100 kWh battery storage system with a symmetrical 100 kW charge/discharge capability and includes seven participants—residential buildings, a carpentry workshop, and an oil mill. The PV feed-in capacity in this region is approximately 280 kW. As in Gasen, Siemens PAC devices are utilized for high-resolution electrical measurements.
Both pilot regions are characterized by high photovoltaic (PV) penetration, which leads to substantial utilization of grid limits—particularly with respect to voltage stability. To address these challenges, the PARMENIDES project explores alternatives to conventional grid expansion. Flexibility provided by the Hybrid Energy Storage System (HESS) is managed via a fully automated, grid-supportive energy management system. This system incorporates load and generation forecasts as well as results from distribution system state estimation (DSSE) to optimize the operation of both the grid and local assets in a grid-friendly manner.
In both Austrian pilots, a communication architecture based on the MQTT protocol is employed. This choice is driven by the compatibility of both Siemens PAC measurement devices and energyLIVE adapters with MQTT. Measurement data from customer installations and grid nodes, along with status information from the HESS, are transmitted via local and cloud-based MQTT brokers.
Central software components such as EMS4HESS and Grid Capacity Management (GCM) subscribe to relevant data channels, continuously receiving and processing measurement data. Based on load and generation forecasts, as well as a detailed grid model, the GCM calculates dynamic power limits that ensure secure grid operation. Within these boundaries, EMS4HESS determines optimal setpoints for the flexibilities available in the HESS. These setpoints—such as those for stationary, grid-supportive storage systems—are transmitted to the respective field devices via the MQTT broker.

The power limits calculated by the Grid Capacity Management (GCM) module are defined for a 24-hour period with a temporal resolution of one minute. Operational control by EMS4HESS is executed in 15-minute intervals. Prior to implementation, a local Clipper module validates the proposed setpoints to ensure compliance with the grid constraints defined for the project. If necessary, the setpoints are adjusted (“clipped”) accordingly. The validated setpoints are then transmitted to the field devices via the MQTT broker. This coordinated process enables dynamic and grid-compatible utilization of flexibilities within the project’s energy communities.
EMS4HESS leverages a PECO instance from the pilot projects as its knowledge base and supports modular deployment scenarios—including cloud-based, on-premises, and hybrid configurations—allowing flexible adaptation to varying application requirements. In the Austrian pilots, a fully cloud-based architecture was implemented due to centralized data communication via an MQTT broker. Communication between EMS4HESS and the central MQTT broker is facilitated by a dedicated MQTT connector. Weather forecasts and real-time data are sourced from an external service and a locally installed weather sensor. Forecasts for generation and consumption are generated hourly with a 15-minute resolution, while the optimization algorithm runs every 15 minutes to update the HESS setpoints.

RESULTS

As described in the previous section, a range of measurement data is collected within the grid. These data are essential for the functionality of both the Grid Capacity Management (GCM) and EMS4HESS systems. They serve as the basis for forecasting grid-supportive power limits for the storage system and for planning the optimal deployment of available flexibilities.

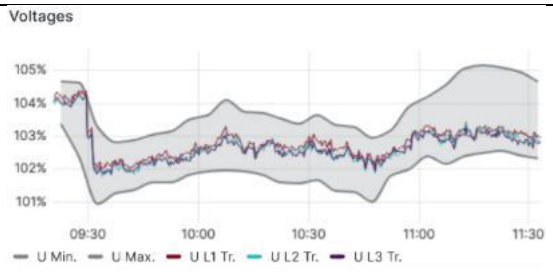


Fig. 1: Voltage measurements of the project energy community and at the transformer (example)

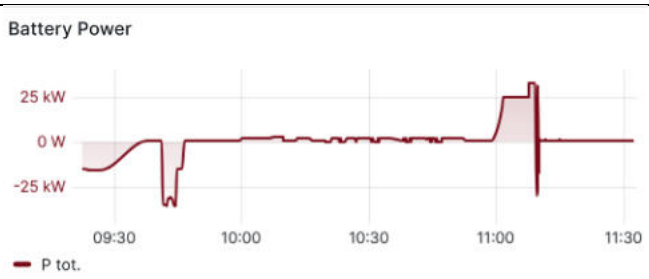


Fig. 2: Exemplary charging/discharging power of the battery storage system based on the optimized operational strategy

Figure 1 illustrates exemplary voltage measurements from members of the project energy community (shown as a grey band), as well as the voltage levels of the three phase conductors at the transformer. EMS4HESS schedules the operation of the HESS based on the grid limits calculated by the Grid Capacity Management (GCM) module. Figure 2 presents a representative time series of the charging/discharging power of the deployed battery storage system, demonstrating the system's ability to reliably implement the prescribed setpoints.

SUMMARY AND OUTLOOK

The PARMENIDES project demonstrates how hybrid energy storage systems (HESS) can be efficiently integrated into energy communities through semantic interoperability. Using the PECO ontology, seamless data exchange between systems is enabled. The developed EMS4HESS optimizes the deployment of storage assets, thereby enhancing resilience and sustainability. The pilot projects confirm the practical viability of the solution. Feedback from the demonstrations is incorporated into the ongoing development of the ontology to adapt it to national requirements and emerging application scenarios.

REFERENCES

[1] Stefan, M., Šipetić, M., Giordano, F., Korner, C., Payonga, L.C., Emiliani, V., Niccolai, L., Aigner, M. (2025): Optimizing Renewable Energy Communities through Ontology-driven Energy Management Systems, CIRED 2025, Geneva, Italy

[2] Aigner, M., Stefan, M. (2025): Parmenides - Plug & plAy eneRgy ManagEmeNT for hybrID Energy STorage, OVE-Energietechnik-Tagung 2025, Innsbruck, Österreich

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CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
1.12 Next-Generation Technologies for Renewable Energy and Resource Efficiency

PERFORMANCE EVALULATION OF A PHOTOVOLTAIC SHUTTER SYSTEM: A DEMONSTRATOR STUDY

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SUMMARY

This project presents the design, construction and evaluation of a photovoltaic (PV) shutter system for windows, developed as a demonstrator to evaluate its performance through both simulation and real-world measurements. The PV shutter combines energy generation with daylight control, providing shading while simultaneously producing electricity. To assess its effectiveness, simulations were conducted to compare the indoor illuminance and glare conditions achieved with the PV shutter. The results highlight the potential of PV-integrated shading systems to balance visual comfort and daylight availability while enhancing building energy efficiency. This demonstrator serves as a proof-of-concept for innovative façade systems that combine occupant comfort with renewable energy integration.

Keywords: *PV-integrated shading systems, performance evaluation, demonstrator study*

INTRODUCTION

Buildings represent one of the largest contributors to global energy demand, especially for heating, cooling, and lighting [1]. In recent years, there has been increasing interest in building components that serve dual functions: dynamic shading and on-site energy generation. Photovoltaic-integrated shading systems (PVIS), such as shutters with PV modules embedded, offer promise for reducing solar heat gain, improving daylighting, and generating renewable electricity.

For example, Roshanak Roshan Kharrat [2] demonstrated that optimizing shading geometry and orientation allows dynamic or responsive shading systems to maintain occupant comfort while maximizing energy gains. Similarly, other studies highlight the trade-off between shading depth and energy demand, emphasizing the importance of optimizing both geometry and orientation [3].

This project aims to explore this balance through a demonstrator study of a PV shutter system, designed to explore the potential of PV-integrated shading solutions. The system is simulated in Rhinoceros 3D® [4] and the RadiCal framework [5]. The empirical evaluation, based on multiple performance measurements, was conducted at the rooftop façade testing facility of the AEE – Institute for Sustainable Technologies in Austria. The study evaluates how effectively the control strategy balances electrical output, thermal comfort, and daylight quality by comparing simulation results with measured performance.

DEMONSTRATOR

The PV shutter system was modelled using the construction software SolidWorks [6], allowing for precise representation of its geometry and kinematics. The demonstrator is equipped with two actuators: the first lifts the PV shutter between its minimum and maximum vertical positions, while the second adjusts the angle of the lower PV module from vertical to horizontal. This angular adjustment enables optimal orientation of the PV module relative to the sun, enhancing energy generation under varying solar conditions. The demonstrator was installed on a test measurement cell at the AEE – Institute for Sustainable Technologies, providing a controlled

environment for performance evaluation. During the measurement period, the system was monitored to assess daylight availability within interior spaces (illuminance measurements), mitigation of glare to maintain visual comfort (HDR images), solar heat gains (in winter) and prevention of overheating to ensure thermal comfort (in summer), and electricity generation from the PV modules under fluctuating solar conditions. This experimental setup allows for a direct comparison between simulated and measured performance, providing valuable insights into the effectiveness of the control strategy and the real-world behaviour of the PV shutter system.



a) b)

Figure 23: Modelled PV shutter demonstrator in SolidWorks a) and installed demonstrator on the test measurement cell b).

RESULTS

The preliminary results indicate that the PV shutter demonstrator has strong potential for both effective energy generation and the enhancement of indoor lighting conditions while mitigating glare. Although the full set of measurements is still ongoing until end of October 2025, initial observations suggest that the system can balance electricity production with daylight provision and visual comfort. These early findings are consistent with simulation predictions and provide a solid basis for the final analysis once the complete dataset is available. Final results will be presented in the full paper and conference presentation.

REFERENCES

Ricci, A., Ponzio, C., Fabbri, K., Gaspari, J. & Naboni, E. (2021). Development of a self-sufficient dynamic façade within the context of climate change. *Archit. Sci. Rev.* 64(1–2), 87–97. https://doi.org/10.1080/00038628.2020.1713042

Roshanak Roshan Kharrat, Giuseppe Perfetto, Roberta Ingaramo, and Guglielmina Mutani; Optimizing Building Performance with Dynamic Photovoltaic Shading Systems: A Comparative Analysis of Six Adaptive Designs; Smart Cities 2025, 8(4), 127; https://doi.org/10.3390/smartcities8040127

Ahmad Baghdadi and Maher Abuhussain, In-Depth Analysis of Photovoltaic-Integrated Shading Systems' Performance in Residential Buildings: A Prospective of Numerical Techniques Toward Net-Zero Energy Buildings, Buildings 2025, 15(2), 222; https://doi.org/10.3390/buildings15020222

McNeel, Robert, et al. 2010. “Rhinoceros 3D, Version 6.0.” Robert McNeel & Associates, Seattle, WA.

Rüdisser, D. (2023) *RadiCal - A novel method to model energy flows induced by solar radiation*. Graz University of Technology. https://doi.org/10.13140/RG.2.2.35641.54882.

Dassault Systèmes, SolidWorks, Version 2024, Waltham, MA: Dassault Systèmes, 2024

CONFERENCE TOPIC

1.02. Building the Future: Smart Energy Infrastructure for the Energy Transition or 1.15. Sustainable Renovation and Energy Retrofits

FROM LAB TO GRID: OPERATING A SORPTION HEAT STORAGE SYSTEM IN A DISTRICT HEATING NETWORK

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Keywords: Energy storage, thermochemical heat storage, district heating, development and testing

SUMMERY

The Heat2Share project successfully demonstrated one of the most advanced sorption-based heat storage systems in Europe. The fully functional demonstrator features modular and scalable storage units integrated into an existing district heating network. Using $CaCl_2$-impregnated activated carbon composites, the closed system offers high energy density and low-temperature operation. With proven material performance and system integration, Heat2Share sets a new reference for thermochemical storage — with the potential to become a benchmark for closed adsorption storage systems on a global scale.

INTRODUCTION

To increase the share of renewable energies in the building sector, innovative thermal energy storage systems are essential – especially for the integration of fluctuating renewable heat sources into district heating systems. Among emerging technologies, thermochemical storage systems (TCS) based on closed adsorption offer significant advantages: high energy density, loss-free standby, and modular scalability. Until recently, however, practical deployment was limited due to material-related challenges, system complexity, and a lack of validated large-scale demonstrators.

The German research project Heat2Share addressed these challenges by developing and building a modular, containerized thermochemical storage system. The system was successfully integrated into an existing biomass-powered district heating grid in Barenthin (Brandenburg, Germany). Designed for operation in the low-temperature range (50–90 °C), the system demonstrated its potential to store and distribute renewable heat efficiently within real district heating infrastructure. The project marked a major step towards the practical implementation of sorptive storage technologies in municipal and industrial applications.

SYSTEM DESIGN AND APPROACH

The developed thermochemical energy storage system was designed as a modular, closed adsorption-based storage unit using a composite material of activated carbon impregnated with 30 wt% calcium chloride ($CaCl_2$). This material was selected due to its high water uptake capacity and suitability for the relatively low temperature range of district heating applications. The system was designed to meet the specific boundary conditions of the Barenthin district heating network, which is operated by a 420 kW CHP unit fed by biogas and supplies 29 buildings. Daily fluctuations in demand, especially morning and evening peaks, required a flexible storage concept capable of load shifting. The core of the system consists of four sorption modules integrated into two units (s. Fig.1). Each adsorption module is equipped with a finned tube heat exchanger surrounded by the sorbent

material. Water vapour is supplied from dedicated evaporators and condensed in shared condensers. The entire setup was installed in a container unit with an integrated control, monitoring, and hydraulic system.

RESULTS AND DEMONSTRATION

The system was installed and hydraulically integrated into the Barenthin heating network in March 2024. A tailored automation system allows fully automatic operation, with charging and discharging processes triggered based on real-time data from the network. Remote access and cloud-based data monitoring enable detailed performance evaluation and further system optimisation. The automated control system enables remote operation, and the system has undergone multiple complete charging and discharging cycles since commissioning. Initial operational data confirm the technical feasibility of using the selected $CaCl_2$-based composite material in real-world conditions. The adsorption capacity measured in lab-scale testing was confirmed during system operation. Thermal cycling and control behaviour follow the predictions from simulation models. The container-based layout proved effective for installation and integration in rural infrastructure environments.
Due to the complex thermal interactions in the district heating network, data collection and validation are ongoing. The full performance evaluation — including energy efficiency, cycle stability and material degradation — will be presented based on extended monitoring over the 2024 and 2025 heating seasons.

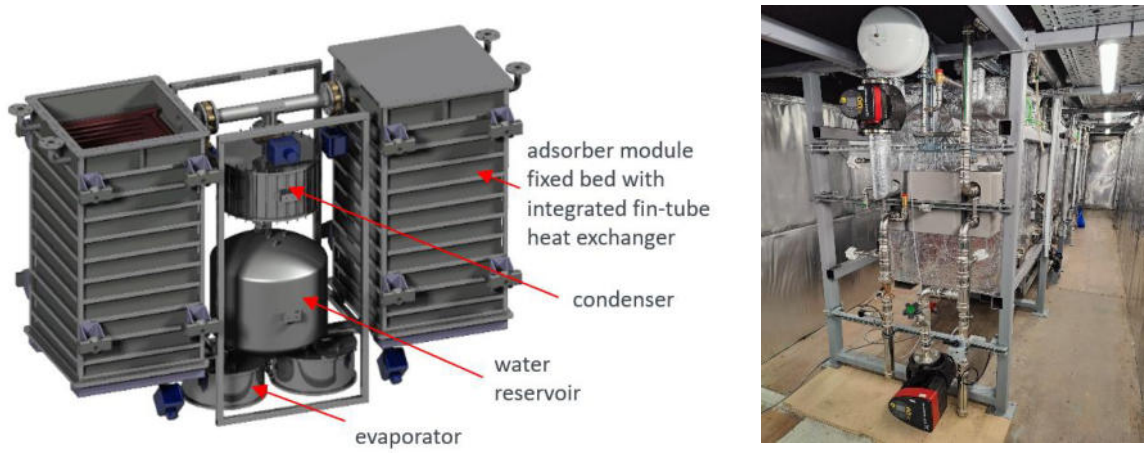


Fig. 1: Adsorption unit with two adsorber modules (left), view inside the container (right)

CONFERENCE TOPIC

1.08 Future District Heating and Cooling Solutions
1.13 Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications
Emerging Heat and Cold Storage

WASTE HEAT UTILISATION IN AUTOMOTIVE FACTORIES: FROM ON-SITE HEAT COVERAGE TO DISTRICT HEATING CONTRIBUTION

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SUMMARY

This study investigates temperature-specific waste heat potentials in automotive factories, classified into vehicle assembly and component production factories. Waste heat is categorised according to whether its temperature level allows direct integration into the factory's heating system or requires upgrading via heat pumps. Vehicle assembly factories exhibit homogeneous shares of directly usable waste heat between 4 and 9 % of their annual heat demand, while indirectly usable potentials range from 7 to 40 %. Component factories show much greater variability, with indirectly usable potentials reaching up to 176 %. A dynamic case study illustrates the annual coverage potential of waste heat at one factory, identifies periods of full internal demand coverage, and quantifies surplus heat that could be exported to a district heating network. The results highlight the value of factory-level data and time-resolved analysis for determining the share of waste heat usable on-site and the surplus available for integration into district heating, both contributing to the decarbonisation of thermal energy supply.

INTRODUCTION

Waste heat recovery is one of several key strategies for decarbonising industrial heat supply, including in large-scale manufacturing sectors such as the automotive industry [1], [2]. In automotive production, waste heat arises across a broad range of temperature levels. Its usability depends on whether it can be directly integrated into the factory's heating system or requires upgrading via heat pumps, as well as on the match between waste heat availability and on-site demand, which defines the potential for external recovery.

While many studies assess industrial waste heat potentials at sectoral or national scale, they often rely on aggregated data and overlook temperature levels, seasonal variation, and factory-specific integration feasibility [3], [4]. Recent research has emphasised the need for localised, time-resolved analyses to understand practical recovery constraints and valorisation options, including dynamic matching with district heating systems [5], [6], [7]. This study addresses these gaps by using real-world operational data from eight automotive factories and one district heating network. Potentials are clustered by integration feasibility based on temperature and end-use compatibility. One factory is examined in detail through a dynamic case study assessing the match between heat supply, internal demand, and external recovery over the year.

METHODOLOGY

Temperature-specific waste heat potentials were evaluated for eight automotive factories. Temperature and thermal power data came from continuous monitoring systems or short-term measurements, the latter scaled to annual profiles. The analysis used data from January to December 2023. Waste heat sources at or above 100 °C were classified as directly usable; lower-temperature sources required heat pump integration. Potentials were expressed relative to each factory's annual heat demand.

One of the vehicle assembly factories was selected for detailed analysis. The necessary simulation model included hourly profiles for internal heat demand, waste heat generation, and the thermal load of a connected district heating network. The software TOP-Energy was used to perform the simulation. Heat pumps were modelled

using Carnot efficiency with a performance factor of 50 %, representing typical losses compared to the theoretical maximum under ideal conditions [8].

RESULTS

Figure 1 shows the temperature-specific waste heat potentials of eight automotive production factories, expressed as a percentage of each factory's annual heat demand. Directly usable waste heat (blue), typically air-based and from high-temperature processes, ranges from 0 to 16 %. Indirectly usable waste heat (orange), mostly water-based and accessible via heat pumps, varies more widely and reaches up to 176 %.

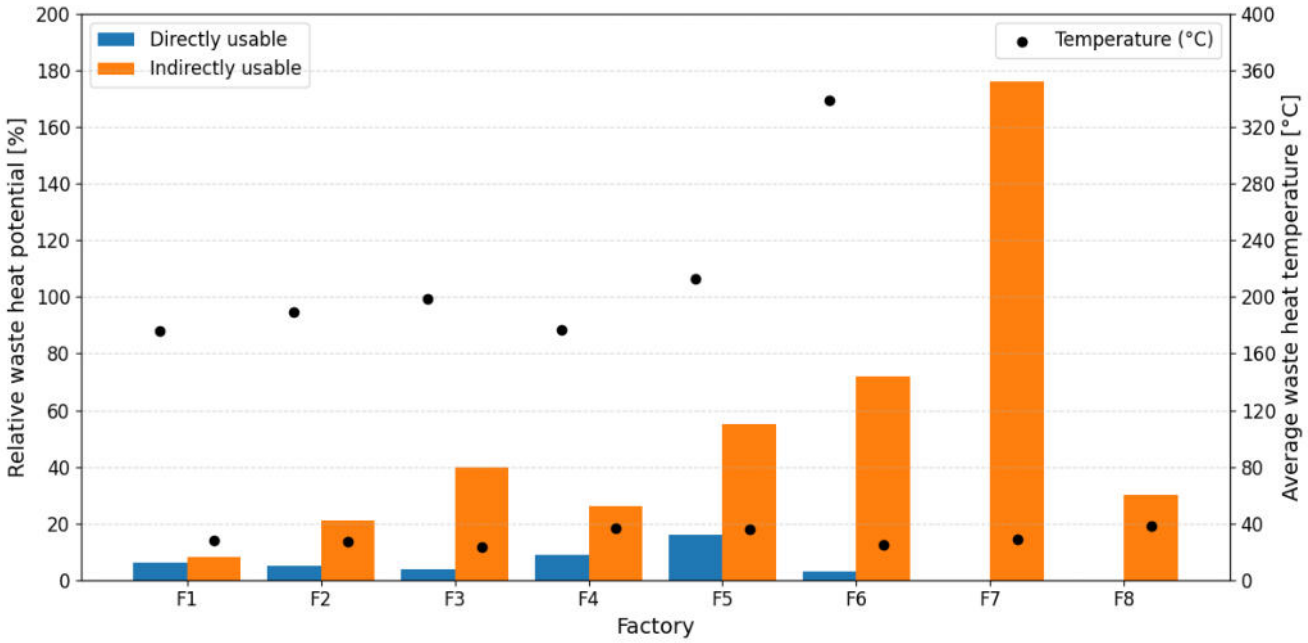


Fig. 1: Relative waste heat potential (directly and indirectly usable) and average waste heat temperature, normalised to the annual heat demand of eight automotive production factories.

The vehicle assembly factories F1 to F4 show similar shares of directly usable waste heat between 4 and 9 %, with average source temperatures from 176 to 200 °C. These streams originate from thermal post-combustion in paint shops and are only available during production hours. Indirectly usable potentials in F1 to F4 range from 7 to 40 % and stem from water-based cooling systems operating between 24 and 36 °C.

In contrast, the component factories F5 to F8 exhibit greater variability. F5 and F6 provide directly usable waste heat between 3 and 16 %, with source temperatures up to 340 °C, while F7 and F8 offer none due to the absence of high-temperature processes. Indirectly usable waste heat is present at all four factories and ranges from 30 to 176 % of the annual heat demand. The overall variation reflects the diverse process structures typical of component manufacturing.

A dynamic simulation for one vehicle assembly factory revealed that 57 % of its annual heat demand can be covered by waste heat—5 % directly and 52 % through heat pump integration. Overall, 69 % of the total available waste heat can be used internally. From early June to mid-September, the entire factory demand can be met with waste heat alone, with an additional 18 % available for export to the district heating network. However, 13 % remains unused due to the absence of thermal storage and insufficient external demand.

These findings demonstrate that temperature and temporal characteristics are decisive for industrial waste heat utilisation. In the automotive production context, directly usable sources are limited and highly process-dependent, while lower-temperature heat, although more abundant, requires technical upgrading and temporal alignment with internal or external demand. The case study confirms that most of the available waste heat is

likely to be reused on-site, with only a limited surplus remaining for integration into district heating systems. This underlines the need for factory-specific, time-resolved planning approaches that assess availability and constraints, and support future evaluations of utilisation concepts and cross-sectoral coupling.

REFERENCES

[1] Papapetrou, M., Kosmadakis, G., Cipollina, A., La Commare, U., & Micale, G. (2018). Industrial waste heat: Estimation of the technically available resource in the EU per industrial sector, temperature level and country. Applied Thermal Engineering, 138, 207–216.

[2] Bianchi, G., Panayiotou, G., Aresti, L., Kalogirou, S., Florides, G., Tsamos, K., Tassou, S., & Christodoulides, P. (2019). Estimating the waste heat recovery in the European Union Industry. Energy, Ecology and Environment, 4, 211–221.

[3] Brückner, S., Arbter, R., Pehnt, M., & Laevemann, E. (2017). Industrial waste heat potential in Germany—a bottom-up analysis. Energy Efficiency, 10(2), 513–525.

[4] Kosmadakis, G. (2019). Estimating the potential of industrial (high-temperature) heat pumps for exploiting waste heat in EU industries. Applied Thermal Engineering, 156, 287–298.

[5] Pelda, J., Stelter, F., & Holler, S. (2020). Potential of integrating industrial waste heat and solar thermal energy into district heating networks in Germany. Energy, 203, 117812.

[6] Burg, V., Richardet, F., Wälty, S., Roshandel, R., & Hellweg, S. (2024). Mapping local synergies: Spatio-temporal analysis of Switzerland's waste heat potentials vs. heat demand. Energies, 17(1), 106.

[7] Manz, P., Kermeli, K., Persson, U., Neuwirth, M., Fleiter, T., & Crijns-Graus, W. (2021). Decarbonizing district heating in EU-27+ UK: How much excess heat is available from industrial sites? Sustainability, 13(3), 1439.

[8] Ahrendts, F., Drechsler, B., Hendricks, J., Küpper, J., Lang, S., Peil, T., Scholz, D., Timofeeva, E., Utri, M., Weidinger, L., Kraus, A., Weiß, U., & Müller, S. (2023). Roll-out von Großwärmepumpen in Deutschland.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: Excess Heat and Resource Recovery from Low-grade Sources, Industrial and Urban Symbiosis

INTEGRATED COUNTERFLOW HEAT EXCHANGER FOR EFFICIENT DOMESTIC HOT WATER IN LOW-TEMPERATURE DISTRICT HEATING

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SUMMARY

The LINK3 Integrated Counterflow Heat Exchanger (ICHE) enables hygienic domestic hot water (DHW) supply with very low primary circulation volumes and significantly reduced return temperatures by maintaining stratification and exergy in the storage tank. Field results from a district heating network demonstrate a primary volume of approximately 17 m³/MWh, compared to 35–50 m³/MWh in other connections within the same network. This corresponds to a reduction in primary mass flow of up to 66 %, a reduction in pumping electricity of about 96 %, and a reduction in pressure losses of around 88 %. These outcomes align with the EU Green Deal and the revised Energy Efficiency Directive (European Commission, 2023) that steers district heating and cooling (DHC) toward full decarbonisation by 2050 and prioritises efficiency and lower system temperatures.

Keywords: low-temperature district heating, stratification, exergy, DHW, 4GDH, 5GDHC, sector coupling

INTRODUCTION

Conventional DHW solutions—storage tanks with integrated coils or plate heat exchangers (PHEs)—involve compromises: coil-in-tank registers are robust but performance-limited and prone to thermal mixing, while PHEs deliver high output at low supply temperatures but require additional pumps and valves and are maintenance-intensive. The mixing of temperatures inside the storage tank destroys exergy, reduces the usable temperature levels, and increases network flow rates.

The new LINK3 ICHE technology combines simplicity and robustness with high transfer efficiency by integrating a counterflow coil into a stratification-preserving storage tank. With its patented exchanger design and unique characteristics, ICHE directly supports the priorities of 4th Generation District Heating (4GDH) (Lund et al., 2014)—operation at lower temperatures, exergy efficiency, and smart grid integration—while paving the way for 5th Generation District Heating and Cooling (5GDHC) (Lindhe et al., 2022) concepts focused on ultra-low temperatures and bidirectional, storage-centered operation.

METHODS AND TECHNOLOGY DESCRIPTION

Operating principle of the domestic hot water heat exchanger: During the draw-off process, the integrated coil induces a thermal annular gap flow. The movement generated at the primary-side heat transfer surface increases the specific transfer capacity disproportionately to the tapping power. As a result, draw-off peaks produce the lowest discharge temperatures in the storage tank, which in turn lead to low return temperatures to the district heating network.

Due to the concentric and integrated design, the heating-water return is introduced slowly into the lower storage volume through a large inflow cross-section (annular gap), preventing turbulent mixing.

Stratification-preserving devices: Two essential arrangements ensure stratification within the storage tank:

- The injection and extraction of mass flows from connected generation and consumption circuits.
- The possibility of complete flow decoupling of circuits operating at different temperature levels.

Firstly, horizontal diffuser outlets provide expansive entry of flows into the tank, while extractions are carried out via horizontally concentrated outlets. This prevents turbulence and preserves exergy. Secondly, up to three stratification layers are available, using specially shaped plates that prevent vertical mixing of mass flows between temperature zones. Owing to the special design of the stratification layers, thermally rising heating water is not impeded from moving upward.
Control and regulation: Counterflow heat exchanger technologies such as plate heat exchangers normally require pumps, valves, flow switches, and control components. In contrast, the ICHE relies on the physical laws of thermodynamics and fluid mechanics, reducing maintenance and servicing needs to a minimum.
Hygiene: Owing to its special construction, the ICHE generates high turbulence on the potable-water side (inside the tube), which inhibits biofilm formation, the basis for microbial growth. Moreover, the thermal fluctuations between operating and standby conditions further suppress biofilm development. The characteristics of the new heat exchanger (ICHE) unite energy efficiency, peak performance, and hygienic safety for the first time. Even with increasing tapping loads maximum performance accross all three aspects is achieved.

RESULTS AND COMPARATIVE PERFORMANCE

Field evidence: At LINK3 deployments such as the Alpendorf network, the primary volume per MWh is ~17 m³/MWh, versus 35–50 m³/MWh for conventional substations. In the network and building-scale cases, Hotel Haven and Netz Nord, average DH return temperatures are ~39 °C (summer) and ~37 °C (winter) for a 300 kW station, and 36-44 °C in a 600 kW segment. This is evidence of high exergy utilisation and deep ΔT extraction. LINK3 sites report ~66 % lower primary mass flow, ~96 % lower pumping electricity, ~88 % lower pressure loss, and fewer components (~80 % less) than PHE-based stations.
Literature consistently finds that lower return temperatures are central to 4GDH performance, enabling lower supply temperatures, reduced losses, and better plant efficiency; yet return-temperature control at substations is often the limiting factor, especially with DHW draws and poor storage stratification. (Chandra et al.2019, Han et al., 2009) LINK3 directly targets that bottleneck.
Latest DHW substation evidence: Studies on domestic hot water preparation from low-temperature district heating in Denmark demonstrate that DHW operation significantly affects network ΔT and return temperatures. Optimized exchanger and storage concepts improve energy, economy, and exergy performance, underscoring the value of designs that preserve stratification and maximize temperature spread, as done by LINK3 (Yang et al. , 2016).

DISCUSSION

The recast of the Energy Efficiency Directive (2023) tightens the definition of “efficient DHC” and targets a fully decarbonised sector by 2050, with Fit-for-55 raising ambition to –55% greenhouse gases by 2030. LINK3’s documented reductions in flows, pumping energy, and return temperatures contribute directly to these objectives by enabling lower system temperatures, better generator COP/condensing operation, and reduced distribution losses.
4GDH → 5GDHC bridge: LINK3 turns each substation into a stratified thermal battery, improving load shifting/peak shaving and facilitating anergy-ready operation with boosters/heatpumps—hallmarks of 5GDHC demonstrations.
Benchmarking significance: International case work frequently reports difficulty in pushing down district heating return temperatures due to DHW events and storage mixing; LINK3’s ~36–44 °C return temperatures under real loads show good results in accordance with such studies and standards.
System & OPEX impacts: By decreasing the mass flow by ~66 % and cutting pumping electricity by ~96% (site data), networks can down-rate pumping, reduce pressure drops, and simplify stations. These are key factors for scalable roll-out of low-temperature district heating. These outcomes are consistent with the 4GDH literature’s emphasis on hydraulic optimisation and exergy-aware design.

Sector coupling: Beyond heating, LINK3's ability to preserve exergy and deliver very low return temperatures creates synergies with electricity and mobility sectors. By enabling lower distribution temperatures and integrating stratified thermal storage, LINK3 substations can flexibly absorb renewable electricity via heat pumps, or release stored heat for grid balancing. This aligns with the EU's sector coupling agenda (European Commission, 2020; Lund et al., 2021), where thermal networks act as hubs linking power, heat, and mobility. In practice, LINK3 enables district heating networks to become active participants in energy system integration: they can store excess renewable electricity as heat, provide balancing capacity during peak demand, and couple with cooling applications – essential features for achieving climate neutrality under the Green Deal.

CONCLUSION

Evidence from multiple LINK3 installations shows order-of-magnitude improvements in hydraulic efficiency and exergy preservation relative to conventional DHW substations, directly supporting EU policy trajectories for efficient, low-temperature, renewables-ready DHC. In international context, LINK3 uses 4GDH principles and provides a practical stepping stone toward 5GDHC by pairing deep ΔT extraction with stratified storage and minimal auxiliary energy. The result is lower returns, lower flows, simpler assets, and higher resilience, a strong fit for Green-Deal-aligned heat transitions.

REFERENCES

Chandra,Y.P., Matuska, M. (2019). Stratification analysis of domestic hot water storage tanks: A comprehensive review. Energy and Buildings, Volume 187, 15 March 2019, Pages 110-131. https://doi.org/10.1016/j.enbuild.2019.01.052

European Commission. (2020). A European Green Deal. Retrieved from https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

European Commission. (2023). Directive (EU) 2023/1791 on energy efficiency. Official Journal of the European Union. https://eur-lex.europa.eu/eli/dir/2023/1791/oj/eng

Han, Y.M. & Wang, R.Z. & Dai, Y.J., (2009). Thermal stratification within the water tank, Renewable and Sustainable Energy Reviews, Elsevier, vol. 13(5), pages 1014-1026, June. https://doi.org/10.1016/j.rser.2008.03.001

Lindhe, J., Javed, S., Johansson, D., & Bagge, H. (2022). A review of the current status and development of 5GDHC and characterization of a novel shared energy system. Science and Technology for the Built Environment, 28(5), 595-609. https://doi.org/10.1080/23744731.2022.2057111

Lund, H., Werner, S., Wiltshire, R., Svendsen, S., Thorsen, J. E., Hvelplund, F., & Mathiesen, B. V. (2014). 4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems. Energy, Volume 68, 15 April 2014, Pages 1-11. https://doi.org/10.1016/j.energy.2014.02.089

Lund, H., Østergaard, P. A., Connolly, D., Mathiesen, B. V., & Alberg Østergaard, P. (2021). Smart energy and smart energy systems. Energy, Volume 137, 15 October 2017, Pages 556-565. https://doi.org/10.1016/j.energy.2017.05.123

Yang, X., Li, H., & Svendsen, S. (2016) Energy, economy and exergy evaluations of the solutions for supplying domestic hot water from low-temperature district heating in Denmark. Energy Conversion and Management Volume 122, 15 August 2016, Pages 142-152 https://doi.org/10.1016/j.enconman.2016.05.057

CONFERENCE TOPIC

1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

TECHNOECONOMIC ANALYSIS OF HIGH TEMPERATURE CARNOT BATTERY RETROFIT INTO SEVERAL DISTRICT HEATING CHP PLANTS

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Retrofitting high-temperature Carnot batteries (CBs) into existing district-heating combined heat and power (CHP) plants can unlock medium-duration storage while leveraging sunk assets. Building on our prior CHP-integrated CB modelling and costing framework, we extend the analysis to multiple representative configurations, including integration with original coal fired steam system, gas-fired combined-cycle CHP (CCGT-CHP) and parallel operation that preserves the option of original fuel firing for security of supply and peak coverage. We formulate a unified dispatch and sizing optimization using a pyomo/HERON–RAVEN toolchain with perfect-foresight windows, site-specific heat-load profiles, and historical day-ahead electricity prices. Performance is assessed in P2H2P and P2H2CHP modes with a common component library (electric heater/charger, high-temperature packed-bed TES, discharge HXs/HRSG, steam cycle), and technoeconomic outcomes are reported primarily as NPV, specific CAPEX, annual cash-flow composition, and effective round-trip efficiency to heat and power. For the CHP systems with optimal electricity arbitrage additionally LCOH.

A structured sensitivity analysis spans carbon price, fuel price (gas/coal), electricity network tariffs (transmission/distribution charges), and heat price, mapping break-even regions for storage duration and charger rating. Across sites, the CB-CHP configuration consistently shifts revenues toward heat sales, while retained-fuel parallel operation expands feasible operating envelopes during adverse power-price spreads and high network charges. For CCGT-CHP retrofits, TES-assisted steam generation reduces part-load penalties and increases flexibility without sacrificing the ability to run on gas during scarcity or system-stress events. Results highlight: (i) storage durations of roughly one daily cycle tend to maximize NPV under realistic tariffs; (ii) carbon price escalation improves CB-CHP competitiveness against fuel-only CHP; and (iii) distribution charges hinders the arbitrage value, elevating the importance of proper policy for energy storage systems. The paper concludes with several recommendations and policy implications for accelerating CB retrofits in Central-European district-heating systems.

TTES MODEL VALIDATION FOR COMMERCIAL-SCALE PROJECTS PERFORMANCE GUARANTEE

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SUMMARY

This abstract presents a TTES model validation work with measurements from large tanks in operation. This study showed good overall results regarding the energy transiting in the storage, with deviations lower than 5%. It illustrated the importance of increasing the number of layers to represent more accurately the temperatures for a multi-node model. This study marks the first step of further stages which assess the ability of this model to be used for performance guarantee protocol.

INTRODUCTION

Thermal Energy Storages (TES) are crucial in heating plants, to balance production and demand by offering flexibility to the system. They represent a strong potential for heat decarbonization, especially Large TES (LTES), which are investigated in several Horizon Europe projects such as TREASURE, INTERSTORES, PUSH-IT and in IEA ES TCP Tasks such as Task 45 (IEA ES TCP – Task 45).
Newheat is a renewable and sustainable heat supplier, which develops, designs, builds, finances and operates renewable heat plants, for major heat consumers worldwide: industrial sites and district heating networks. The company currently has 7 sites in operation for a total of 45 MW of solar thermal fields installed.
Modelling is one of Newheat core activities, as it is necessary to support all the phases of project development, by offering the possibility to do dynamic simulation of renewable heat plants. An in-house proprietary library called NewLib has been developed in Modelica language within the Dymola Environment, for internal purposes and is based on the ThermoFluidStream library (Dirk Zimmer et al., 2021).

MODEL & METHOD

The TTES is modelled using a multi-node modelling approach, the storage is discretized in layers, which respect the following energy balance, based on the thermal inertia, convection in the storage, conduction between layers and heat losses to the outer environment (Eq 1):

$$\frac{\partial T(z,t)}{\partial t} + v\frac{\partial T(z,t)}{\partial z} = \frac{\lambda}{\rho C_p}\frac{\partial^2 T(z,t)}{\partial z^2} + \frac{\dot{q}_{los}}{\rho C_p} \quad (1)$$

After this model development, its validation was a crucial part to determine its accuracy and its potential use for performance guarantee between Newheat (storage supplier) and a client who wants to make sure that it will perform according to expectations. The following steps have been taken:

- Validation against data from the LACTOSOL solar plant TTES on a typical operation period to evaluate the global model performance (energy balance and temperatures within the storage).
- Cross comparison with models from IES ES TCP Task 39 (IEA ES TCP – Task 39) to evaluate NewLib model against other reference models from literature.
- Validation against heat recovery plant TTES during shutdown period (focus on TTES heat losses).

Finally, the ability of the TTES model to commit to guarantees is discussed through sensibility analyses. This last step is ongoing and its final results will be presented in the full paper.

RESULTS

In this abstract, only the validation results against LACTOSOL data are introduced. This solar plant provides renewable heat to the Verdun site of Lactalis Ingredients. It is the largest French solar thermal plant supplying an industrial site. This plant's TTES has a volume of 3'000 m^3, a height of 12 m and 20 cm rockwool insulation. Operation data from May 2024 over a ten-day period have been used. The validation has been conducted for two cases, 24 and 96 layers. Table 1 compares the unoptimized (Un-Opt.) and optimized (Opt.) power results using MMSGO (surrogate-based optimization algorithm, referenced also as Optimized or Opt.). Table 1 also compares the results of the un-optimized, MMSGO, GA, and SQP simulations using the same input data. When comparing simulation methodologies, both the mean and the standard deviation must be considered. The advantage of applying global search optimization approaches in optimizing SG models is demonstrated in Table 1 by the estimated power mean and STD results. Overall, the results demonstrate that MMSGO outperforms GA and SQP in terms of limiting grid fluctuations (lower STD values), but power loss is nearly identical for each simulation. showcases the energy balance for both cases compared to measurements.

Table 1: Energy balance and deviations between measurements and simulations.

	Measurements	24 layers simulation		96 layers simulation	
Type of value	Absolute [MWh]	Absolute [MWh]	Relative [%]	Absolute [MWh]	Relative [%]
Charged energy	198.7	189.3	- 4.7%	194.3	- 2.2%
Discharged energy	237.2	238.7	+ 0.6%	241.0	+ 1.6%
Heat losses	9.9	4.5	- 54.2%	4.5	- 54.3%

The transiting energies deviate from less than 5% for both configurations, while the simulated heat losses show high deviations as they are twice as big as the measured ones. Figure 24 presents temperatures within the TTES:

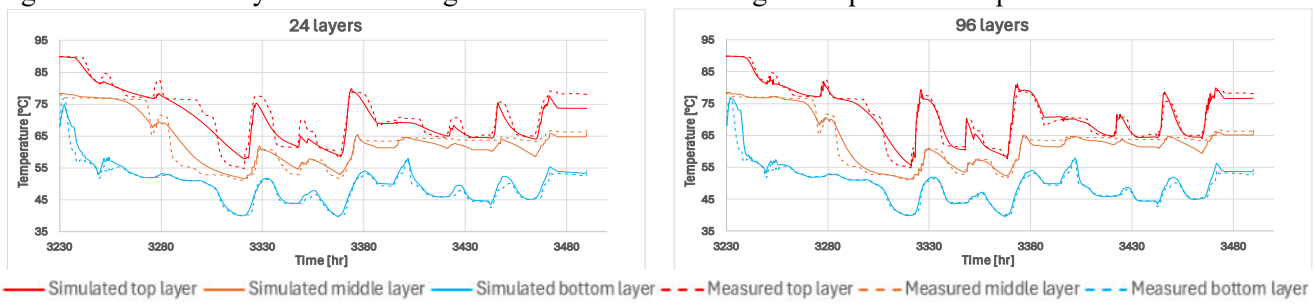


Figure 24: Simulation and measurement layers temperature comparison for 24 and 96 layers

The average Mean Absolute Error and Root Mean Square Error respectively decrease from 1,67 to 1,09 and from 2,26 to 1,64 between TTES models with 24 and 96 layers. The 24 layers graph shows a good overall tendency, but we notice that increasing the layer numbers to 96 is quite better to get a good concordance with measurements.

CONCLUSION

This first step of validation work illustrates that the TTES model is satisfying for system simulation as the deviation for charged and discharged energies are relatively small. It also shows the importance of a high layer number (96) to model accurately the temperatures within the storage. High deviations are noticed for the heat losses; however, the other validation tests point that the insulation parameters used in the simulation are probably too optimistic compared to real-life materials. The results presented in this abstract are a first glimpse into a more thorough work to develop a reliable and robust performance guarantee procedure which uses this TTES

REFERENCES

Dirk Zimmer, Niels Weber, & Michael Meißner. (2021). *The DLR ThermoFluidStream Library*. 225–234. https://doi.org/10.3384/ecp21181225
IEA ES TCP-Task 45 - Accelerating the Uptake of Large Thermal Energy Storages https://iea-es.org/task-45/
IEA ES TCP-Task 39 - Deliverable C2a: Modelling guidelines - Round robin test case description (for comparative simulations) https://iea-es.org/task-39/

CONFERENCE TOPIC

This article refers to conference topic 1.13. “Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage”.

SWITCH TO CIRCULAR ECONOMY IN GLOBAL VALUE CHAINS AS PART OF THE ENERGY TRANSITION

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SUMMARY

The global Switch to Circular Economy Value Chains (SWITCH2CE) project aims for a just transition to an inclusive, climate neutral and circular economy, focusing on selected global value chains. It serves as an enabler of alliances between EU multinationals, their suppliers from developing countries, target country governments and the EU to enable change towards a circular future. The target value chains are textile and garments, plastic packaging and electronics.

With the project entering its final stages, important learnings are being consolidated on innovative partnerships with the corporate sector and their in-country suppliers, academia and the financial sector to de-risk investments and inform governments on institutional reforms needed to scale and mainstream the transition, with respect of the socio-economic implications. Finally, the results highlight the opportunity to combine efforts on the circularity and energy transitions towards industrial decarbonization.

INTRODUCTION

SWITCH2CE started in 2021 and is expected to run until early 2027. The project is co-funded by the European Union and the Governmenmt of Finland, with a total budget of €20,870,000. The expected impact is:

- Increased material efficiency and related environmental benefits incl. reduced GHG emissions
- Competitiveness of local value chain actors increased through innovation and new business models
- Green jobs created or sustained
- Investments leveraged and pipeline developed

Working with leading multinationals and their local suppliers, SWITCH2CE pilots innovative solutions to reduce waste, boost recycling, and unlock new opportunities for sustainable growth. Circular value chain transformations also require a supportive landscape of circular economy-friendly policies, finance mechanisms, skills, consumer awareness and platforms for collaboration. Therefore, the SWITCH2CE pilot projects are complemented with activities that create an enabling environment for inclusive circular transitions in the target countries and beyond.

Four innovative pilot projects are currently in different stategs of completion:

Plastic packaging in Morocco: The pilot with Equatorial Coca Cola Bottling Company (ECCBC) is setting up a scalable bottle-to-bottle collection and recycling scheme to advance circular economy approaches in plastic packaging

*Textile & Garments in Bangladesh:*The pilot with BESTSELLER is is scaling up traceable textile recycling by capturing and reintroducing post-industrial textile waste into new collections. Another pilot with H&M Group is recycling blended textile waste (cotton and polyester) into new garment making and establishes an ethical and traceable waste supply chains for recycled polyester (rPET).

ICT & Electronics in Egypt : The pilot with Orange and Nokia aims to create a high-quality standard secondary market for mobile devices and network equipment including the establishment of refurbishment facilities

An overview of ongoing pilot projects is provided in Figure 1.



Fig. 1: Overview of ongoing SWITCH2CE pilot projects

To ensure lasting impact, these pilots are complemented by initiatives that strengthen the enabling environment to scale and mainstream the circularity solutions. SWITCH2CE partners with leading knowledge institutions Chatham House, Circle Economy Foundation and the European Investment Bank to support policy dialogue and capacity building, equip financial institutions to design green financing solutions, and empower local academia and service providers to help businesses adopt circular practices. Together, these efforts are paving the way for a more resilient and sustainable textile value chain in in the target countries. Scaling and complementary initiatives are currently being prepared for roll-out in the final project year, including with new corporate partners and in additional countries. This integrated intervention logic is schematically shown in Figure 2.

The full paper and/or oral presentation will elaborate on the key learnings at global level and across value chains and will dive into the detail of a country- or value-chain specific example to demonstrate the lessons learned and aim to synergize future energy and circular transition projects in their industrial decarbonization efforts.

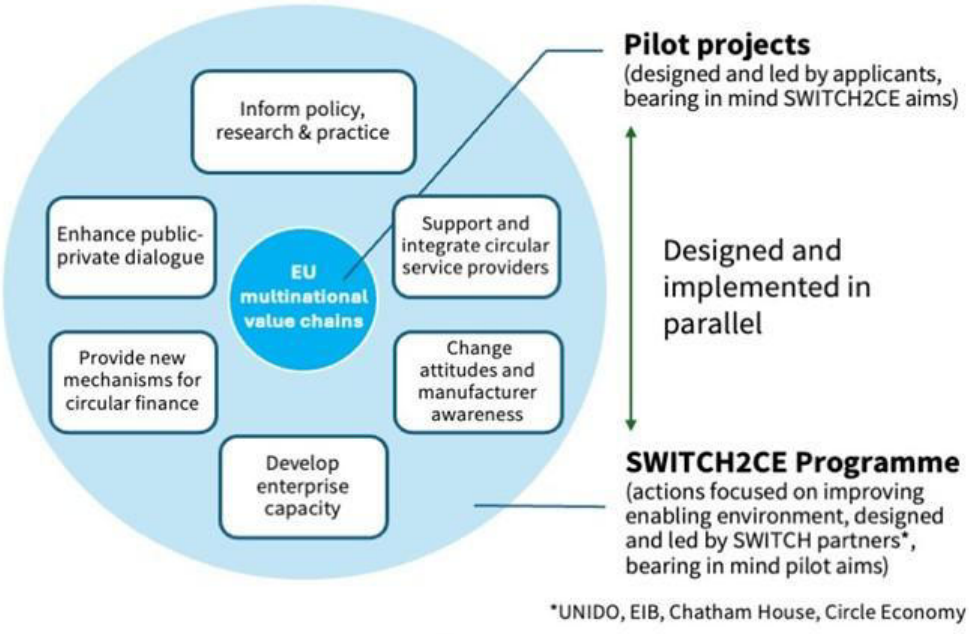


Fig. 2: SWITCH2CE intervention logic for lasting impact

REFERENCES

https://www.switchtocircular.eu/
www.unido.org

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

- The transition toward sustainable circular economies

"GOING CIRCULAR" - CIRCULAR ECONOMY & TECHNOLOGY DEVELOPMENT AT WIEN ENERGIE USING THE EXAMPLE OF "WASTE2VALUE"

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SUMMARY

Wien Energie is investigating the Waste2Value Dual Fluidized Bed (DFB) Gasification technology to produce sustainable energy carriers from both biological and fossil feedstocks. A 1 MW demonstration plant operated at Wien Energie's waste incineration site in Simmering, Vienna, Austria, enables testing of various materials, supported by simulations and pre-trials at TU Wien. A reference simulation converting woody biomass to Fischer-Tropsch (FT) syncrude showed promising efficiencies (carbon: 53.7%, energy: 61.3%). Feedstock screening narrowed the focus to forest wood chips, waste wood, and plastic waste, with economic feasibility and availability guiding the selection. Scaling is being considered, but due to market uncertainties, a monitoring approach is currently favored.

INTRODUCTION

In the face of accelerating climate change and an increasingly volatile geopolitical landscape, the urgency to develop sustainable and resilient energy technologies has never been greater. The dual pressures of environmental responsibility and energy security demand innovative approaches to producing sustainable energy carriers. Biological feedstocks offer a promising pathway toward climate-neutral fuels, while plastic components from recycling processes allow for a circular economy business models and reduce dependence on fossil-based imports. A very flexible technology enabling the processing of both biological and fossil feedstocks to produce a variety of potential products, from synthetic natural gas (SNG) to kerosene components, is the "Dual Fluidised Bed Gasification" technology called "Waste2Value" investigated by Wien Energie. Its scaling could not only contribute to global decarbonization goals but also present strategic opportunities Wien Energie to enhance autonomy.

Recent techno-economic assessments indicate that the conversion of woody biomass to SNG may be financially viable under certain conditions. However, fluctuating funding landscapes and market price uncertainties suggest that a cautious approach is warranted. Rather than immediate scale-up, ongoing monitoring of economic and policy developments is essential to ensure long-term feasibility and strategic alignment.

DEVELOPMENT WORK AT WIEN ENERGIE

At the Syngas Platform Vienna, operated by BEST – Bioenergy and Sustainable Technologies (Syngas Platform Vienna) in partnership with Wien Energie, a 1 MW-scale demonstration plant has been used to evaluate the suitability of various biological and fossil feedstocks for the production of Fischer-Tropsch syncrude. The facility integrates three core components: a gasification unit, a gas cleaning system, and an FT synthesis reactor. Through intensive weeklong testing campaigns, the plant enables real-world validation of feedstock performance, syngas quality, and FT product yields. These trials are essential for understanding the operational dynamics and scalability of synthetic fuel production from diverse input materials.

Complementing the demo plant activities, pre-testing and simulation work is conducted at TU Wien. A 100 kW-scale gasification reactor operated by TU Wien allows for controlled trial runs, while advanced process simulations support mass and energy balance calculations. These preparatory steps help optimize feedstock

selection and process parameters before full-scale testing, reducing risk and improving efficiency. Together, the collaboration between BEST and TU Wien provides a robust framework for developing sustainable fuel technologies that could be integrated into Wien Energie's future energy portfolio. In cooperation with Dieffenbacher GmbH, scaling considerations are considered during testing campaigns. Because of international interest in the technology, non-domestic biomass like coconut shells and cashew nut shells are also tested.

A process simulation was conducted to evaluate the conversion of wood chips into FT syncrude, representing a reference pathway for renewable fuel production. The simulation assumes a feedstock input of 16.6 tonnes per hour of woody biomass. The system shows an internal electricity demand of 4.5 MW. The process chain includes DFB gasification, gas cooling and coarse cleaning, fine syngas purification, CO_2 separation, FT synthesis, product separation, and tail gas steam reforming.

The simulation yields 2.1 tonnes per hour of FT syncrude and thermal energy for district heating (5.5 MW). Key performance indicators derived from the simulation include an overall carbon efficiency of 53.7% and an overall energetic efficiency of the process is calculated at 61.3%, indicating a promising route for renewable fuel production from woody biomass, albeit with significant energy and material input requirements.

A comprehensive feedstock screening was conducted to identify suitable materials for thermochemical conversion to synthetic fuels. The initial longlist included a diverse range of biological and fossil-based materials such as straw, reed, animal meal, corn cobs, paper fiber rejects, sugarcane bagasse, municipal solid waste, glass fiber-reinforced plastics, sewage sludge, bark, and refuse-derived fuels. Following this assessment, a refined shortlist was established, comprising forest wood chips, waste wood, and plastic waste. As a result, many process chains from feedstock to product were eliminated either because the feedstock availability cannot be guaranteed, or the financial feasibility is not foreseeable. Therefore, a monitoring process regarding the input variables for the economic assessment was established, with woody biomass to SNG already being a promising future process route.



Fig. 1: Waste2Value plant at Wien Energie in Simmering, Vienna, Austria

CONFERENCE TOPIC

1.03. Circular Economy Strategies for the Energy Transition

TRANSFORMATION TO SUSTAINABLE CLINKER PRODUCTION THROUGH MODEL-BASED CONTROL AND REAL-TIME RECIPE OPTIMIZATION

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SUMMARY

This work presents the successful industrial implementation of an automated, model-based quality control system for CO_2-optimized raw meal production at the Wietersdorf cement plant. The system enables the use of up to 45% alternative raw materials (ARM) while maintaining consistent product quality. It combines inline analytics, automated recipe optimization, and advanced material flow management to proactively stabilize raw meal composition. The control system was validated under both standard and high ARM rates, demonstrating its robustness and effectiveness. This innovation contributes to industrial decarbonization and represents a milestone in sustainable clinker production.

Keywords: Recipe optimization; Alternative raw materials; CO_2 reduction; Inline analytics; Raw meal production; Clinker production

INTRODUCTION

The cement industry is responsible for approximately 3.5% of Austria's national CO_2 emissions, primarily due to the calcination of carbonate-based raw materials and the combustion of fossil fuels [1, 2]. Strategies to achieve climate-neutral cement and concrete production focus on reducing process and fuel-related emissions, optimizing cement recipes, and implementing carbon capture technologies.

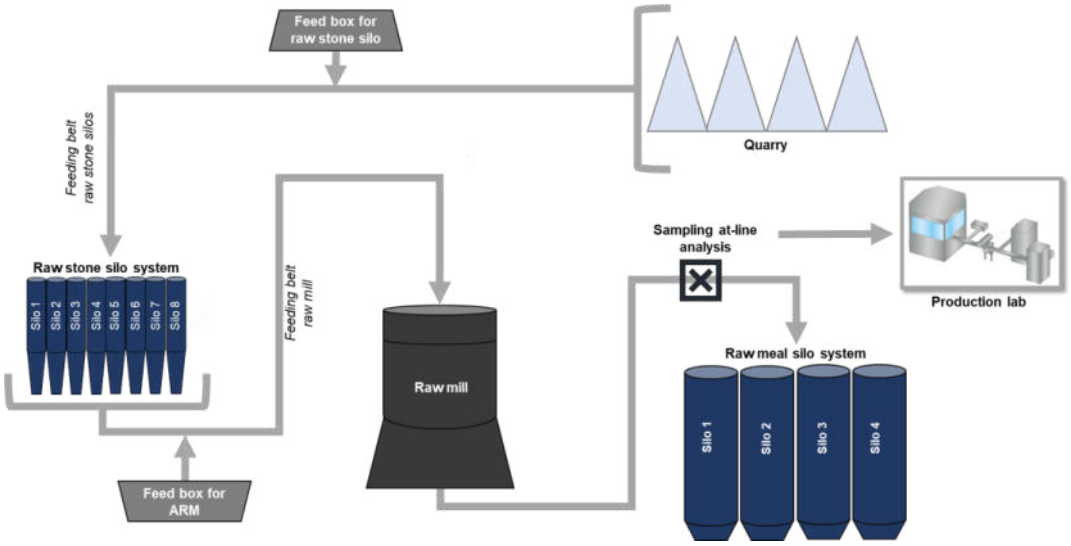


Fig. 1: Schematic plant setup of the raw meal production process

Reducing process emissions is achieved by the substitution of primary raw materials with low-CO_2 alternatives [3, 4]. The project focuses on replacing primary carbonate-containing raw materials with CO_2-reduced alternative

raw materials, rather than merely capturing emissions afterward. However, the high variability of ARM poses significant challenges for process control. Without large-scale homogenization, fluctuations in raw material composition can disrupt kiln operation and affect clinker quality.

Therefore, a precise, automated any fully digitized control system is essential to ensure stable production under increasing ARM rates.

PROJECT DESCRIPTION

The project was implemented at the fully integrated Wietersdorf cement plant, which operates without a conventional blending bed and instead uses a complex system of 25 dosing units, including 13 raw material silos, 10 fine material silos, and 1 slurry silo. This configuration allows for the simultaneous use of up to 25 different components, including highly variable ARM.

To manage this complexity, a multi-layered process control system was developed in [5]. It includes:

- Inline analysis using two cross belt analyzers for real-time monitoring of the feedstock's chemical composition
- A virtual silo model that tracks material flow and composition using first-in-first-out logic and GPS-based quarry data.
- A mathematical optimization algorithm that minimizes raw meal costs, including CO_2-related costs, while respecting process constraints and quality specifications.
- A web-based expert system that calculates optimized raw meal recipes and communicates setpoints directly to the DCS (PCS 7) via OPC-UA/MQTT.

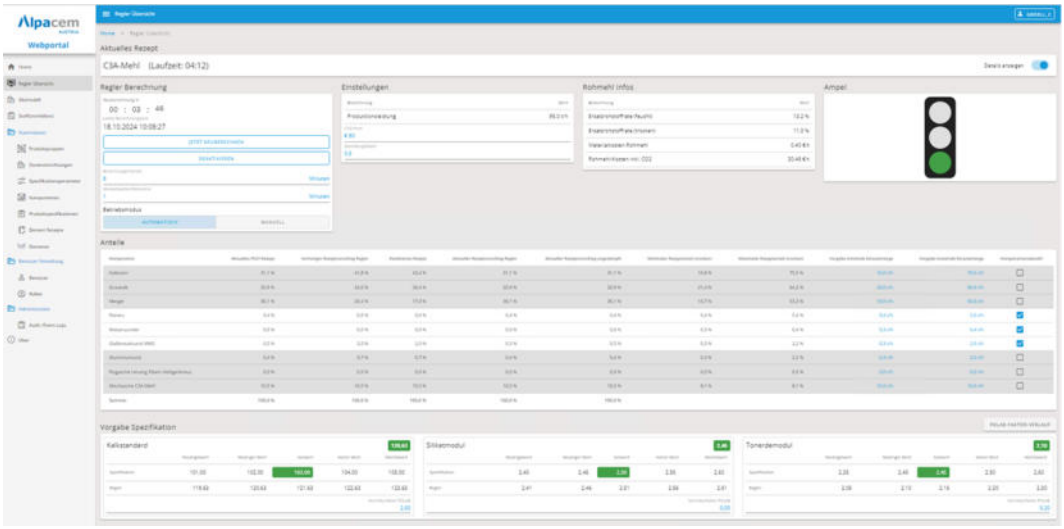


Fig. 2: User interface to web portal

The system was validated through industrial-scale trials. The system achieved stable raw meal quality with reduced standard deviation of the lime standard by 26%. CO_2 content in raw meal was reduced by up to 18.6% compared to industry averages. The control system reached high technology readiness, transitioning from Excel simulation to fully automated web-based software. It enabled consistent production with up to 45% alternative raw materials, demonstrating robustness and scalability.

The system is fully implemented at the Wietersdorf plant and adaptable to other cement plants with similar infrastructure. A successful pilot trial confirmed technical feasibility with over 45% ERS use.

Its modular design and reliance on commercially available analyzers make it scalable both domestically and internationally in plants with comparable setup. Domestically, the project addresses Austria's cement sector, with the Wietersdorf site alone expecting to reduce emissions by 51,107 tonnes annually. By targeting emissions at the source, it offers scalable and sustainable impact across the industry. The project was tailored to cement plants without large scale homogenization capabilities and its results are applicable in the industry.

The approach can easily be transferred to any mixing or blending problem in process industry where high frequent inline analysis data is available and the composition, prices and/or availability of recycled secondary raw material is fluctuating.

REFERENCES

[1] Kestler, P.: Treibhausgas-Bilanz Österreichs 2021. Rückblick auf die Emissionen 2021, Ausblick auf 2022, 2030 und 2040. https://www.umweltbundesamt.at/news230123 (2023).
[2] Mauschitz, G.: Emissionen aus Anlagen der österreichischen Zementindustrie. Berichtsjahr 2022, Wien. https://www.zement.at/downloads/downloads_2023/Emissionen_aus_Anlagen_der_österreichischen_Zementindustrie_Bilanzjahr_2022.pdf (2023).
[3] Feiz, R., Ammenberg, J., Baas, L., Eklund, M., Helgstrand, A., Marshall, R.: Improving the CO2 performance of cement, part I: utilizing life-cycle assessment and key performance indicators to assess development within the cement industry. Journal of Cleaner Production (2015). https://doi.org/10.1016/j.jclepro.2014.01.083
[4] Feiz, R., Ammenberg, J., Baas, L., Eklund, M., Helgstrand, A., Marshall, R.: Improving the CO2 performance of cement, part II: framework for assessing CO2 improvement measures in the cement industry. Journal of Cleaner Production (2015). https://doi.org/10.1016/j.jclepro.2014.01.103
[5] Gröll, C. (2025). Entwicklung eines automatisierten Qualitätssteuerungskonzepts zur Rohmehlproduktion in mischbettlosen Zementwerken unter Einsatz variabler Ersatzrohstoffraten. [Dissertation, Montanuniversität Leoben (000)]

CONFERENCE TOPIC

Topics this abstract refers: 1.03. Circular Economy Strategies for the Energy Transition

CIRCULARFOOD: CASCADING UTILIZATION PATHWAYS OF FOOD PROCESSING RESIDUES AND VALORIZATION POTENTIALS OF BIOGAS DIGESTATES

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Keywords: food processing residues, cascading use, biogas digestates, liquid fertilizer, peat substitute, circular economy

SUMMARY

In Austria, approximately 1.3 million tonnes of unavoidable organic by-products from food processing are generated annually. These residues are predominantly used for animal feed or biogas production. The **CircularFood** research project pursues a cascading approach to optimize the use of these residual streams. Within the project, plant proteins are first extracted, the remaining fractions are subjected to biogas fermentation, and the digestates are subsequently valorized into liquid fertilizers and peat-free substrates. Initial results demonstrate that pre-treatment by protein hydrolysis enables comparable or even enhanced methane yields. At the same time, novel value chains are established through bio-certified liquid fertilizers and climate-friendly substrates. Furthermore, peat-free growing media are being developed that substitute peat, thereby contributing to the protection of peatlands and the reduction of CO_2 emissions. CircularFood thus illustrates a practical pathway toward a resource-efficient, circular-oriented food industry.

INTRODUCTION

The food industry is a major producer of organic by-products, which are currently utilized primarily for energy recovery or as animal feed. In the context of global challenges such as climate change, resource scarcity, and the increasing demand for sustainable products, more efficient utilization of these residues is becoming an urgent necessity.

New cascading utilization pathways that maximize both material and energy valorization can help address these challenges. The CircularFood project tackles this issue by developing innovative, cascading approaches that integrate material recovery and energy generation. The focus lies on protein extraction, biogas production, and the upgrading of biogas digestates into liquid fertilizers and peat substitutes.

The CircularFood concept comprises three core process steps, with the present abstract placing particular emphasis on the valorization of the digestate:

1. **Protein Extraction**
   Plant proteins are isolated from residues such as brewers' spent grain or pumpkin seed press cake. These proteins can serve as sustainable alternatives to conventional protein sources in the food industry.
2. **Biogas Production**
   The protein-depleted residues are subjected to anaerobic fermentation. Experimental results indicate that methane yields are not diminished by prior protein hydrolysis; in some cases, they are even increased.
3. **Digestate Valorization**
   The resulting biogas digestates are separated into liquid and solid fractions and subsequently upgraded.

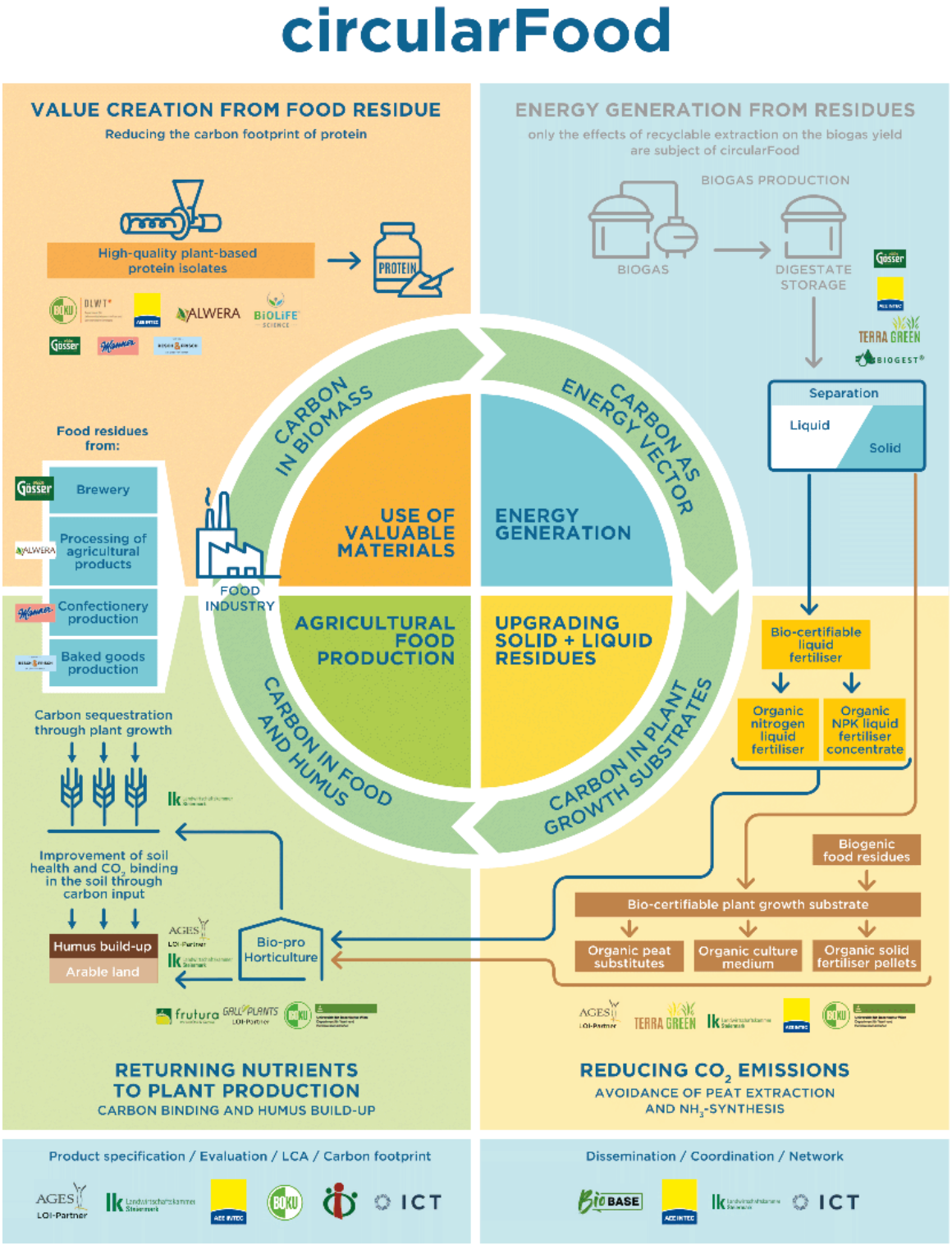


Fig. 1: The project graphic visualizes the complex cycle: food industry residues from breweries, bakeries, confectionery production, and agricultural processing are initially used for protein extraction. This is followed by biogas production, with the resulting digestates forming the basis for liquid fertilizers and bio-certifiable substrates, which are in turn applied in agriculture and horticulture for new food production.

Liquid phase:
The liquid digestate provides the basis for developing bio-certified liquid fertilizers. In the project, digestates from the Göss Brewery were processed in a large-scale trial, generating 50 m³ of liquid fraction for research purposes. A novel bio-NPK liquid fertilizer based on this digestate is currently being tested in field trials with the Styrian Chamber of Agriculture, applied in organic tomato and cucumber production at Frutura greenhouses, and scientifically monitored by BOKU University. Future research will focus on membrane distillation technologies to concentrate the NPK fertilizer and to obtain a highly pure, liquid organic nitrogen fertilizer. For the first time, organic acids such as citric acid are used in fertilizer production, enabling organic certification and enhancing sustainability.

Solid Phase:
In parallel, innovative peat substitute materials and growing substrates are developed from the separated solid fraction of the digestate. Since peat extraction destroys valuable peatlands and releases substantial CO_2 emissions, CircularFood provides a sustainable alternative. The substrates derived from digestates and food residues are designed not only to improve soil health and humus formation but also to contribute to carbon sequestration. In the first project year, Terra Green GmbH and BOKU's Institute of Soil Research worked intensively on optimal blends of novel substrates based on fermented brewers' spent grain. Thus far, a mixture of composted solid digestate fractions with agricultural residues has shown the best results in promoting root development. In cooperation with horticultural companies, the high quality and practical applicability of the developed substrates are being confirmed.

CONCLUSION

The results clearly show that cascading utilization pathways for food residues can generate significant ecological and economic benefits. Preceding protein extraction not only creates an additional value stream but also enhances the efficiency of subsequent biogas production.
Digestate upgrading further provides new opportunities for agriculture. While liquid fertilizers help to close nutrient cycles, peat-free substrates can contribute to reducing CO_2 emissions from peat extraction. CircularFood therefore delivers a practical approach that addresses both the requirements of a circular economy and climate policy.
The CircularFood project demonstrates that interdisciplinary research and cooperation with industry partners can lead to innovative circular solutions that combine ecological and economic benefits. Cascading utilization of food processing residues contributes substantially to a resource-efficient circular economy, reduces CO_2 emissions, and unlocks new value creation potentials.

ACKNOWLEDGEMENTS

Research on the valorization of biogas digestates within the CircularFood project is carried out in collaboration with BOKU University (Institute of Soil Research), Terra Green GmbH, the Styrian Chamber of Agriculture, Göss Brewery, BDI-BioEnergy International GmbH, and horticultural company Frutura.

REFERENCES

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

SECTOR COUPLING OF ELECTRICITY AND HEAT THROUGH SMART DISTRICT HEATING NETWORKS

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SUMMARY

The *#Systemkraftwerk Murau* project demonstrates how district heating (DH) networks in rural alpine regions can become key enablers of integrated renewable energy systems. Within the project four DH networks act as demonstrators to develop and validate sector coupling and flexibility measures. Core innovations include the smart integration of biomass-based heat generation with additional locally available renewable and waste heat sources as well as renewable excess electricity. Specific demonstration measures, that are necessary to achieve these innovations, address reduced system temperatures, decentralized boosters for industrial customers, integration of power-to-heat units (heat pumps and electric boilers), and optimized heating plant operation. These solutions improve plant efficiency, ensure efficient use of biomass, and increase the capacity of heating systems to absorb excess renewable electricity.

INTRODUCTION

The transformation of energy systems toward 100% renewable sources is a major challenge, especially in inner-alpine regions with complex infrastructure and seasonal variability. Since 2003, the Murau region in Austria has pursued a forward-looking energy vision and now generates multiple times its electricity demand from renewables such as hydropower, biomass, wind, and solar. However, these surplus faces infrastructure limits—like constrained grid capacity—leading to curtailments and limiting further expansion.

The *#Systemkraftwerk Murau* project addresses these challenges by creating an integrated regional energy system that supports demand-driven, cross-sector, and resilient energy distribution. Three thematic hubs—electricity (Power to Power), gas (Power to Gas to X), and heat (Biomass Flexibility)—serve as living labs for prototypical model solutions, focusing on flexibility, sector coupling, and system synergies.

The goal is not just regional self-sufficiency but positioning Murau as a reliable energy exporter within national and EU-wide systems. Hereby, the project offers a scalable model for other rural areas striving for decarbonization through smart, integrated, and locally adapted energy solutions.

INNOVATION AND RELEVANCE

The *#Systemkraftwerk Murau* project introduces a system-wide innovation approach centred on rethinking the role of district heating networks in the renewable energy transition. In rural alpine regions, heat provision remains one of the most infrastructure-intensive and carbon-relevant sectors. Within the Biomass Flexibility Hub of the project, the main question is, how existing and future district heating infrastructures can become dynamic components of an integrated, sector-coupled energy system.

Key innovations include the smart integration of biomass-based heat generation with additional locally available renewable and waste heat sources as well as renewable excess electricity. These are combined with advanced thermal storage systems and intelligent control mechanisms, allowing for real-time load balancing and sector

coupling with the electricity system via e.g. power-to-heat (heat pumps and electric boilers) and CHP technologies.
The project also introduces a digital model to simulate, monitor, and optimize district heating system performance across technical, economic, and ecological dimensions. This enables predictive operation, efficiency improvements, and efficient use of biomass.

DEMONSTRATION IN REAL-LIFE DH NETWORKS

Demonstration is a cornerstone of the *#Systemkraftwerk Murau* project, with the Biomass Flexibility Hub acting as the primary area for validating the transformation of district heating systems.
The four biomass-based DH networks in Lachtal, Murau, St. Lambrecht and St. Georgen ob Murau are acting as demonstrators, each with its own individual settings and challenges. Specific aspects addressed include:

- Reduction of feed temperatures of the DH networks, to enable the utilisation of waste heat from CHPs and low-temperature (below 100°C) power-to-heat units. For industrial customers, that require heat at higher temperatures (brewery in Murau and producer of explosives in St. Lambrecht), decentralised boosters and storages will be integrated.
- Integration of power-to-heat systems: Especially from spring to autumn, the load of DH networks is low, due to the decreased heat demand for space heating. This correlates with an increased production of electricity from PV and hydropower during this period. Hence, the utilisation of electricity for heat production for this period is being addressed and included.
- Waste heat integration: different sources such as industry, the river Mur and electrolysers for H_2-production are investigated and concepts for the integration of the waste heat are being developed.

Solutions developed for each demonstrator are simulated and techno-economically evaluated in the first step. These results form the basis for the following realisation and monitoring of the solutions developed. For the *#Systemkraftwerk Murau,* the solutions from the Biomass Flexibility Hub result in a hybrid system for the larger area, capable of switching between sources, depending on availability and cost-efficiency. Large-scale power-to-heat systems with smart controllers will allow the hub to absorb excess electricity from PV, hydropower and wind, directly contributing to sector coupling and reducing grid stress.
Monitoring is complemented by a robust KPI framework, tracking parameters such as primary energy factor, CO_2 savings, supply reliability, economic performance, and user satisfaction. This data is continuously assessed and fed back into system operation and design decisions.
A defining feature of the demonstration is its embedded regionality. Operators of municipal and cooperative heating systems are engaged throughout the process—from technical planning to interface testing and citizen communication. Regular stakeholder workshops and open data sharing ensure community ownership, while also serving as an education and replication platform.

CONCLUSIONS

The final project results are summarized into practical toolkits, covering planning guidelines, economic models, policy briefs, and modular technical templates. These are tailored for replication and will provide a solid basis, especially in other alpine and rural regions seeking to modernize their heating systems while supporting broader national and EU decarbonization strategies.

CONFERENCE TOPIC

- Primary topic: Coupling of Energy Sectors
- Secondary topic: Flexibility and Stability in Thermal and Electric Grids

PVT-READY HEAT PUMPS – DEFINITION AND MARKET OVERVIEW

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SUMMARY

Photovoltaic-Thermal (PVT) collectors, also named hybrid collectors, offer significant potential to boost the efficiency of heat pump systems - provided that heat pumps are optimized to work with them. A recent market study explored the readiness of brine heat pumps for PVT integration, focusing on two operational modes: using PVT collectors as the sole heat source and combining them with geothermal heat sources. As part of the German initiative IntegraTE-XL, the project consortium developed clear criteria for defining "PVT-ready" heat pumps in both configurations. A comprehensive market survey followed, resulting in an overview of products that meet this new definition in various ways. Another aspect of the survey was the market significance of PVT heat pump systems from the perspective of heat pump manufacturers.

SURVEY ABOUT PVT-READY HEAT PUMPS

Eighteen heat pump suppliers, eleven from Germany and seven from neighboring European countries, received a multi-page questionnaire. Nine companies submitted information on their products for the overview: ait-deutschland GmbH, enrgi GmbH, Heim AG, Heliopac, M-TEC GmbH, Nibe Systemtechnik GmbH, Ratiotherm GmbH & Co KG, Triple Solar and Waterkotte GmbH.

In principle, the heat pump manufacturers surveyed agree that PVT collectors can be used as a sole heat source. Three criteria were surveyed for this operating mode (Table 1). The most important criterion for PVT-ready is the wide inlet temperature range for the heat source. Almost all companies meet this requirement for low temperatures in the range of -12 to -20 °C.

However, the approved upper temperatures for the heat source vary significantly between the different types of heat pumps, ranging from 20 to 55 °C. Some suppliers – Heliopac, Ratiotherm and Triple Solar – even allow the brine from the roof to reach 70 °C for a short period of time at the heat pump inlet. Some of the devices therefore require a mixing valve to comply with the temperature limit for the heat source from the PVT collector circuit. This mixing valve is not integrated as standard in any of the heat pumps and must therefore be installed by the installer. Other heat pump suppliers do not require a mixing valve because they have a special design and operation strategy of the refrigeration circuit that takes over the function of a mixing valve (Triple Solar and Ratiotherm).

INITIAL CONCLUSIONS FROM THE SURVEY

The paper provides a definition of PVT-ready of heat pumps in both operating modes – PVT collector as sole heat source and supplementary to a geothermal heat source. It also describes the results of a detailed market overview that examines the PVT readiness of various types of heat pumps (Table 1 shows as an example an

excerpt from this overview). In summary, it can be stated that heat pump manufacturers are much better at meeting the requirements for PVT-ready for using PVT collectors as a sole heat source than they are at source management, which is necessary when PVT collectors and geothermal are available as joint heat sources. In this operating mode, only three heat pump manufacturers have integrated an adequate source management into the heat pump control; all others rely on an additional external controller.

	ait-deutsch-land GmbH	enrgi GmbH	Heim AG Heiz-systeme	Heliopac	M-TEC GmbH	Nibe System-technik GmbH	Ratio-therm GmbH & Co. KG	Ratio-therm GmbH & Co. KG	Triple Solar	Triple Solar	Water-kotte GmbH
Product name of heat pump	alpha innotec - WZSV 63H(K)1/3 M	Eco Geo Pro 2-10	SWM pro 2-13	Solerpac	BHPA412	S1156 / S1256	WP Max-LoQ F27	WP Max-LoQ pF10	Wärme-pumpe 5.0	Wärme-pumpe 10s	5029 Ai
Approved range of inlet temperatures for the heat source for the heat pump	-13 to +30 °C	-25 to +35 °C	-20 to +22 °C	-5 to +50 °C short term up to +70 °C	-15 to +40 °C	-9 to +30 °C	-15 to +55 °C short term up to +70 °C	-15 to +55 °C short term up to +70 °C	-20 to +70 °C	-20 to +25 °C	-15 to +20 °C
Maximum thermal output for B-15W55 according to DIN EN 14511	3.45 kW at B-13/W55	7 kW	7 kW	n/a	6.5 kW (extra-polated)	n/a	13.8 kW	4.5 kW	Approx. 3.6 kW (extra-polated)	Approx. 5.5 kW (extra-polated)	n/a
Can a mixing valve be controlled via the heat pump control system to limit the temperature of the heat source?	no	no	yes	not required [1]	yes	yes	not required [3]	not required [3]	not required [4]	yes	no
Is the mixing valve integrated into the heat pump?	no	no	no	No	no	no [2]	no	no	no	no	no

Table 1: Overview of various heat pumps concerning PVT-ready aspects for PVT collectors as a sole heat source

[1] In continental climate zones, a second heat source in addition to PVT is mandatory.
[2] An external mixing valve is part of the “PVT 40 package”.
[3] An internal intermediate circuit directly in front of the evaporator acts as a mixing valve.
[4] The heat pump has an electronically controlled expansion valve and a dynamic superheat controller, which ensures that the refrigeration circuit can be cooled at minimum compressor speed until the refrigerant has cooled to 50 °C.

IntegraTE-XL is a project funded by the German Federal Ministry for Economic Affairs and Energy that builds on the already completed project IntegraTE (2019 to 2024) and aims to establish PVT collectors combined with heat pumps on the market and promote their use in existing large apartment buildings and commercial properties. Three German research institutes are working together on this topic: the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg, the Institute for Building Energy, Thermotechnology and Energy Storage (IGTE) at the University of Stuttgart and the Institute for Solar Energy Research in Hamelin (ISFH). In addition, 19 industry partners and solrico are supporting the project.

REFERENCES

https://wp-monitoring.ise.fraunhofer.de/integrate/german/index/index.html

CONFERENCE TOPIC

1.04. Coupling of Energy Sectors
1.07. Flexibility and Stability in Thermal and Electric Grids
1.12. Next-Generation Technologies for Renewable Energy and Resource Efficiency
1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications
Emerging Heat and Cold Storage

ADOPTION PATHWAYS AND OPERATION STRATEGIES OF RESIDENTIAL BATTERIES IN EUROPE

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Extended Abstract

INTRODUCTION

The ongoing decarbonization of the energy system is driving fundamental changes in electricity generation, consumption, and storage at the household level. Residential photovoltaic (PV) installations have already achieved significant penetration in many countries, creating new opportunities for decentralized energy production but also introducing challenges for system operation, particularly in distribution grids. In this context, residential battery storage has emerged as a promising technology that can mitigate grid stress while providing direct benefits to households. Batteries allow for the temporal alignment of local PV generation and demand, thereby increasing self-consumption and energy autonomy. At the same time, aggregated residential storage has the potential to contribute to system-wide objectives such as peak load reduction, congestion management, and renewable energy integration.

Research on residential battery storage has expanded, but few studies integrate household and system perspectives (Fett et al., 2021). For Germany, Jägemann et al. (2021) analyse regulatory impacts with optimisation models but assume universal adoption once profitable, neglecting uncertainties and non-financial drivers. In Australia, Say et al. (2019) use household data to simulate optimal PV–battery investments, and Say et al. (2020) extend this with system-level modelling, though limited to a single year (2030). Yu (2018) examines France, estimating costs and demand changes under universal PV–battery adoption, but assumes homogeneous households and omits operational strategies. Diffusion approaches include Klingler et al. (2019), who estimate installed capacities across Europe, and Schwarz et al. (2019), who apply an agent-based model to California but simplify household drivers and market dynamics.

Moreover, the impact of batteries on the grid is not determined solely by the number of systems installed, but also by how these systems are operated (Hartvig, 2025). Household-oriented strategies, such as maximizing self-consumption, may reduce individual electricity costs but exacerbate grid imbalances, while grid-oriented strategies, such as peak shaving, could enhance system stability but provide weaker direct incentives for households. As a result, understanding both the likely diffusion of residential batteries and the implications of alternative operation strategies is critical for guiding policy, business models, and grid planning.

This study contributes to this discussion by projecting the diffusion of residential batteries and assessing their impact on the electricity grid under different operational modes in 25 European countries using the Clean Energy Adoption in the Residential Sector (CLEARS) model. Insights are provided into how adoption dynamics and battery operation strategies jointly shape system outcomes.

METHODOLOGY

The CLEARS diffusion model is employed to project the adoption of residential battery storage systems and to evaluate their aggregate impacts on the electricity grid. The methodology follows a two-stage approach (Hartvig, 2025; Hartvig & Szabó, 2025). In the first stage, household-level financial viability is assessed through a net present value (NPV) calculation. The NPV integrates key household characteristics, such as regional location, load profile, annual consumption, and rooftop PV azimuth, to estimate the benefits of energy storage and surplus generation, alongside technology and installation costs. This step identifies the share of households for which battery investments are financially advantageous.

In the second stage, the potential adopter population derived from the NPV analysis is used as input to regional Bass diffusion models. This ensures that non-financial adoption barriers, such as information gaps and behavioural inertia, are incorporated and that technology uptake follows an empirically grounded S-shaped trajectory.

Finally, adoption projections are linked to grid-level simulations, where different battery operation strategies (self-consumption maximization, and peak shaving) are compared. This enables a systematic assessment of how financial incentives, behavioural diffusion dynamics, and operational choices jointly shape household benefits and system-wide outcomes.

BATTERY OPERATION STRATEGIES

This analysis considers two alternative battery operation strategies. In the *Self-consumption* strategy, electricity stored in residential batteries must be consumed within the household and cannot be exported to the grid. By contrast, the *Smoothed* strategy applies a simplified operational logic designed to flatten daily load profiles. Specifically, it compares the current load to the seven-day rolling median load at the country level: charging is permitted only when demand falls below the median, while discharging, including feeding electricity into the grid, is enabled when demand exceeds the median. Furthermore, the scenario assumes a gradual uptake of this operation scheme, with the participation rate of battery owners rising from 10% in 2026 to 100% by 2050.

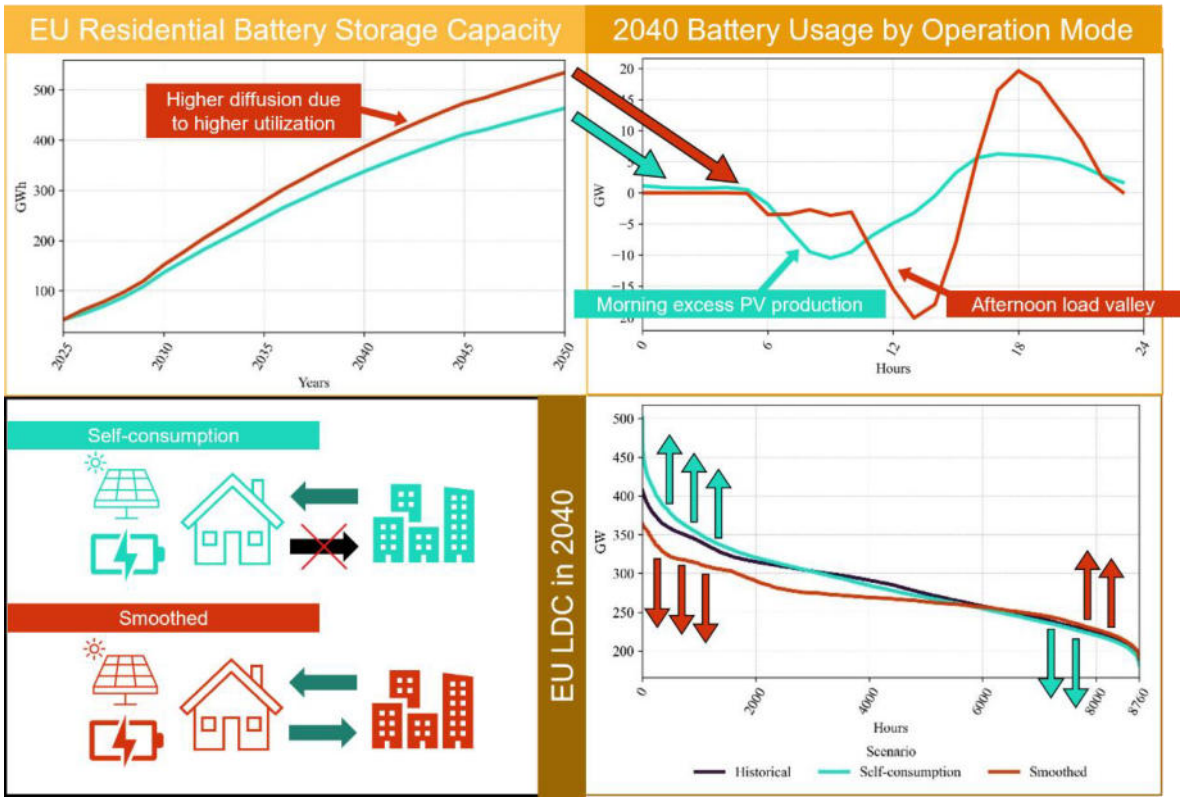


Figure 25 Summary of preliminary results. a) Residential battery capacity in the EU between 2025-2050; b) Average daily battery use patterns by scenario (negative - charging, positive - discharging); c) Schematic overview of the operation modes; d) Load duration curve in the EU by scenario and historical data from 2024.

PRELIMINARY RESULTS

Extending the CLEARS model to 25 EU member states (excluding Malta and Cyprus), residential battery storage capacity is projected to reach approximately 460–530 GWh, depending on the operational strategy applied (see Figure 1). In the *Smoothed* scenario, where electricity can be fed back into the grid, the NPV of residential battery investments is higher, resulting in a faster diffusion compared to the *Self-consumption* scenario.

The impact of residential batteries on the electricity system depends not only on the total installed capacity but also on the operational strategy applied. In the *Self-consumption* scenario, households begin charging their batteries as soon as surplus PV generation becomes available in the morning. From a system perspective, this behaviour is suboptimal, as it coincides with the morning demand peak. Consequently, by the time demand decreases and the afternoon valley emerges, the batteries are nearly fully charged and unable to absorb additional load. In contrast, the *Smoothed* scenario delays battery charging to midday, when demand is lower and solar generation remains abundant. Moreover, this strategy allows for feeding electricity back into the grid, thereby enabling batteries to alleviate evening demand not only by supplying their owners but also by supporting the wider system.

These distinct charging patterns lead to markedly different system-level effects. As illustrated in Figure 1, the *Smoothed* operation strategy effectively mitigates daily peaks as shown on the load duration curve, whereas the *Self-consumption* scenario exacerbates them by synchronising household charging in the morning, thereby shifting the peak load to earlier hours.

Future work will extend the analysis by incorporating additional operational strategies specifically focusing on heating and cooling and by evaluating the potential CO_2 emission reductions. These reductions are expected to result from the increased utilisation of solar energy and the mitigation of peak loads, which are frequently met by gas-fired power plants.

REFERENCES

[1] Fett, D., Fraunholz, C., and Keles, D. (2021). Diffusion and system impact of residential battery storage under different regulatory settings. *Energy Policy*, 158:112543.

[2] Hartvig, Á. D. (2025). Trade-offs in feed-in tariff scenarios for incentivizing clean technologies in Central and Eastern Europe. *Solar Energy*, *294*, 113499.

[3] Hartvig, Á. D., & Szabó, L. (2025). Regional residential battery storage diffusion pathways in Hungary. *Regional Statistics*, *15*(2), 234-257.

[4] Jägemann, C., Hagspiel, S., and Lindenberger, D. (2013). The economic inefficiency of grid parity: The case of German photovoltaics. Technical report, EWI working paper.

[5] Klingler, A.-L., Schreiber, S., and Louwen, A. (2019). Stationary batteries in the EU countries, Norway and Switzerland: Market shares and system benefits in a decentralized world. In *2019 16th International Conference on the European Energy Market (EEM)*, pages 1–5. IEEE.

[6] Say, K., John, M., and Dargaville, R. (2019). Power to the people: Evolutionary market pressures from residential PV battery investments in Australia. *Energy Policy*, 134:110977.

[7] Say, K., Schill, W.-P., and John, M. (2020). Degrees of displacement: The impact of household PV battery prosumage on utility generation and storage. *Applied Energy*, 276:115466.

[8] Schwarz, M., Ossenbrink, J., Knoeri, C., and Hoffmann, V. H. (2019). Addressing integration challenges of high shares of residential solar photovoltaics with battery storage and smart policy designs. *Environmental Research Letters*, 14(7):074002.

[9] Yu, H. J. J. (2018). A prospective economic assessment of residential pv self-consumption with batteries and its systemic effects: The French case in 2030. *Energy Policy*, 113:673–687.

INTEGRATING BUSINESS MODELS, DATA GOVERNANCE, AND TOOLCHAINS TO UNLOCK INDUSTRIAL & URBAN SYMBIOSIS AT SCALE

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SUMMARY

Industrial and urban symbiosis (IS) is a key strategy for reducing emissions, improving resource efficiency, and advancing circular economy transitions. While successful cases demonstrate feasibility, large-scale deployment remains hindered by three systemic gaps: fragmented business models that overlook partner roles and incentive allocation; weak, non-standardized data governance limiting secure and interoperable exchange; and limited adoption of advanced tools due to usability and integration barriers. To overcome these, a framework is proposed around five pillars: (i) expanded business models with standardized contracts, (ii) modular toolchains spanning from screening to operational control, (iii) enforceable data governance agreements, (iv) policy and market enablers such as carbon pricing and incentives, and (v) adaptation to park typologies. Recommendations include template contracts, interoperable data platforms, longitudinal studies, integration of carbon capture and utilization, policy alignment, and cross-typology demonstrations.

INTRODUCTION

Over the past two decades, industrial symbiosis has evolved from an academic concept to a widely endorsed mechanism for enhancing energy efficiency, minimizing waste, and reducing greenhouse gas (GHG) emissions in eco-industrial and urban-industrial systems. Landmark cases, such as Kalundborg and Ulsan, have demonstrated the feasibility of inter-firm material and energy exchanges [1]. Empirical studies have validated the capacity of industrial parks to deliver measurable carbon reductions through infrastructure coordination and cross-sector collaboration [2]. Despite this progress, contemporary deployments continue to face systemic challenges that are insufficiently addressed in the current discourse.

KEY GAPS IN CURRENT PRACTICE AND LITERATURE

A critical analysis of recent developments highlights three underexplored barriers that hinder scalable implementation.

- **Business Model Fragmentation.** Current IS research emphasizes cost savings and resource efficiency but often neglects partner roles, customer value, and incentive allocation. The absence of standardized contracts complicates investment decisions, and while cooperative allocation methods (e.g., Shapley value) offer promise, practical uptake is limited by the lack of templates and clear verification protocols [3].
- **Data Governance Deficiencies.** IS tools rely on detailed energy and material data, yet confidentiality, poor standardization, and limited interoperability restrict exchange. Proprietary systems further reinforce silos. Although ontology-based and decentralized frameworks show potential [4], robust governance with tiered access, anonymization, and third-party validation remains underdeveloped, leaving digital IS strategies incomplete.
- **Tool Adoption and Operational Integration.** Despite the availability of advanced modeling and optimization tools, operational uptake is low due to usability issues, data demands, and implementation complexity. Many tools are abandoned after pilots, reflecting a gap between technical potential and user capacity. Modular toolchains spanning screening, design, simulation, and operations are not yet formalized or widely deployed [5].

A STRUCTURED PATHWAY FOR INTEGRATION

To address these systemic gaps, an integrated framework is proposed around five interconnected pillars:

- **Business Model Expansion.** Introduce multi-actor service models, performance-based contracts, and carbon-credit monetization aligned with emissions trading. Standardized templates with metering and verification can de-risk projects and align stakeholder incentives [6].
- **Modular Toolchain Design.** Structure tools along four stages: 1) screening (e.g., GIS/Sankey), 2) collaborative design (e.g., System Dynamics, trade-offs), 3) investment simulation (e.g., Aspen Plus, MILP/MINLP, LCA), and 4) operational control (e.g., MPC, P2P trading, DR). This supports flexible deployment by maturity, capacity, and data [7].
- **Data Governance Contracts.** Implement role-based access, shared ontologies, and third-party escrow to secure confidentiality and interoperability. Clear agreements with technical and legal backing can overcome cross-firm hesitation [4].
- **Policy and Market Enablers.** Apply incentives such as carbon pricing, tax credits, and co-financing to reduce risk and stimulate investment. Feed-in tariffs for waste heat and bonus-malus schemes can further motivate participation [8].
- **Park Typology Adaptation.** Adjust strategies to local conditions and sectors (steel, petrochemical, data centers, agri-food). Park-specific contexts determine viable tools, governance models, and value chains [9].

RECOMMENDATIONS FOR RESEARCH AND DEPLOYMENT

To operationalize industrial symbiosis at scale, several strategic research and implementation priorities should be pursued:

- **Standardized IS contract templates**. Define frameworks for shared utilities, material exchanges, and carbon credits, including roles, pricing, metering, and risk-sharing. Templates reduce negotiation time and improve bankability.
- **Interoperable data platforms.** Support semantic mapping, secure transfer, and tiered access. Alignment across tools and IT systems can overcome interoperability barriers; pilots should test adoption, data quality, and integration speed.
- **Longitudinal studies in eco-industrial parks**. Track long-term economic, environmental, and organizational outcomes under real policies, focusing on ROI, participation, policy impacts, and resilience.
- **CCUS integration into toolchains.** Embed capture and utilization models within IS frameworks, analyzing siting, synergies with utilities, and cost allocation, while incorporating credit and trading scenarios.
- **Policy alignment with deployment.** Use scenario modeling to test the sensitivity of IS business cases to carbon taxes, subsidies, and trading schemes, enabling policies that reduce risk and support adoption.
- **Demonstrate modular toolchains.** Pilot toolchains across diverse park types, tailoring tools, data needs, and governance. Measure success through energy savings, emissions cuts, user acceptance, and replicability.

REFERENCES

[1] H. Zhang et al., Energy Policy, vol. 61, 2013, pp. 1400–1411.
[2] H. W. Kim et al., Resources, Conservation and Recycling, vol. 135, 2018, pp. 225–234.
[31] V. Andiappan et al., Chemical Engineering Transactions, vol. 45, 2015, pp. 1657–1662.
[4] Industrial Symbiosis Tools and Methods for Low-Carbon Industrial Parks, Scoping Review Report, 2024.
[5] F. Mousqué et al., Computers and Chemical Engineering, vol. 138, 2020.
[6] K. D. T. Aguilar et al., in HNICEM 2017, 2017.
[7] K. W. Tan et al., Chemical Engineering Transactions, vol. 103, 2023, pp. 823–828.
[8] K. R. Cao et al., Int. J. Environ. Res. Public Health, vol. 19, no. 19, 2022.
[9] M. D. Rodriguez et al., Journal of Sustainable Development of Energy Water and Environment Systems, vol. 11, no. 3, 2023.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

1.10. Industrial and Urban Symbiosis

HYBRID PIT THERMAL ENERGY STORAGE FOR SOLAR HEAT AND SURPLUS ELECTRICITY: SYSTEM INTEGRATION, OPERATIONAL STRATEGIES, AND ECONOMIC PERSPECTIVES

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SUMMARY

The transition towards renewable district heating is challenged by volatile gas prices, increasing investment costs, and uncertain market conditions. These developments have reduced the economic feasibility of large-scale thermal storage systems for solar thermal heat, creating an urgent need for innovative and flexible solutions. Within the framework of an ongoing HORIZON project, a large-scale Pit Thermal Energy Storage (PTES) system is being developed to store solar heat and integrate surplus electricity from the power grid using a 10 MW electric boiler. This hybrid approach aims to increase system flexibility, improve renewable energy utilization, enable new operational strategies, and enhance the projects profitability.
However, this additional functionality directly affects the overall system concept, including the dimensioning and operation of key components such as the PTES, the solar thermal field, and the heat pump. To address these challenges, comprehensive system simulations are conducted using TRNSYS to evaluate different charging and discharging strategies, assess the technical performance, and analyse the economic feasibility under varying market scenarios.

INTRODUCTION

Decarbonizing district heating networks is a central challenge in the energy transition, especially as fluctuating renewable energy sources gain importance. While large-scale thermal energy storage enables the integration of renewable heat sources into district heating networks, rising investment costs and persistently low gas prices have significantly impacted the business case for such systems. To make future projects feasible, storage technologies must evolve towards multi-functional, hybrid solutions that create additional value streams.

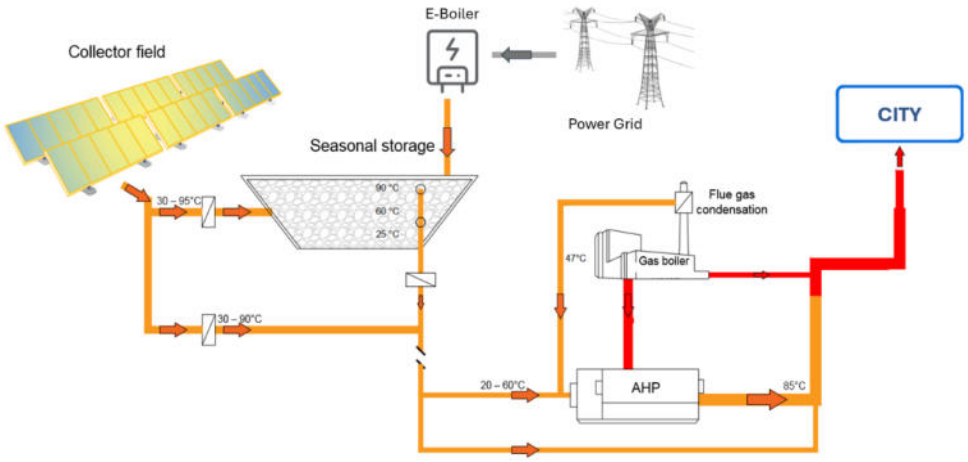
Pit Thermal Energy Storages (PTES) offer high storage capacities at comparatively low specific costs, making it an attractive option for seasonal energy storage. In the presented demonstrator, the PTES is integrated into a hybrid energy system consisting of a large solar thermal field for seasonal charging, heat pump for discharging to the district heating network, and an electric boiler for absorbing surplus electricity from the grid (Figure 1).

The electric boiler enables the storage to act as a flexible energy buffer, linking the electricity and heating sectors. This creates new opportunities for grid stabilization and improved utilization of renewable energy but also introduces significant complexity to the system design and operational strategy.

AIM OF THIS WORK

To address the increased system complexity, TRNSYS-based system simulations are carried out to determine the optimal dimensioning of the PTES, the solar thermal field, the heat pump, and the electric boiler. The simulations also investigate different operational strategies under varying heat demand profiles and electricity price scenarios, while assessing potential revenues from grid flexibility services and surplus electricity integration. Furthermore,

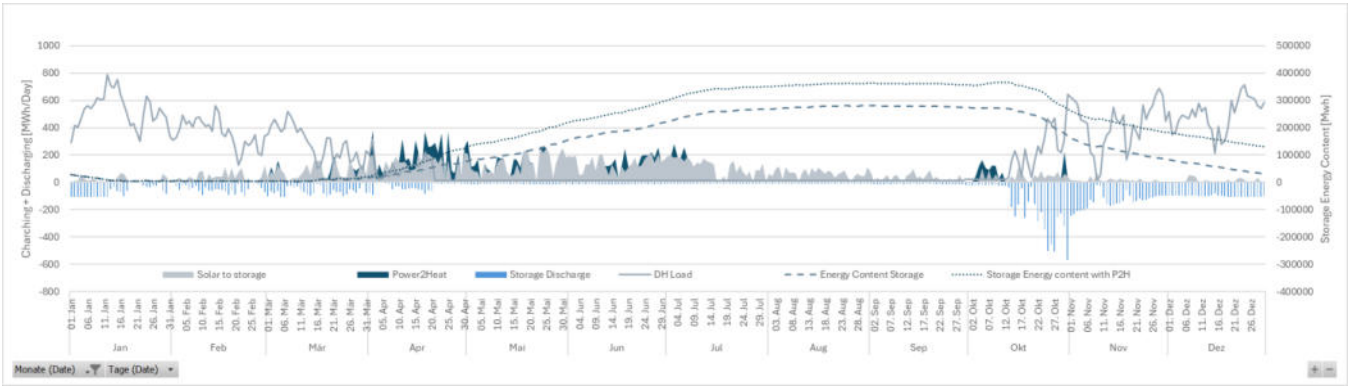
the overall economic performance of the system is evaluated under future market conditions to identify pathways towards a scalable and economically viable solution.



26 SYSTEM CONCEPT

PRELIMINARY RESULTS

Preliminary simulation results reveal that the integration of surplus electricity for grid stabilization significantly increases the complexity of storage management. Unlike the electric boiler, solar thermal production cannot be switched on and off flexibly, leading to operational conflicts between heat generation and power grid requirements. In particular, frequent grid surpluses in summer necessitate a reduction of the solar collector field size to prevent overproduction. However, this reduction must be optimized so that the system remains technically and economically viable even without additional power-to-heat charging. Furthermore, regulatory aspects such as grid access rules, tariff structures, and energy market policies substantially influence the system design and are progressively integrated into the simulations as discussions with grid operators and policymakers continue. Figure 2 shows the daily energy balance of the storage system and highlights the mismatch between storage capacity and additional charging demand when power-to-heat integration is considered.



27 THE FIGURE ILLUSTRATES THE DAILY ENERGY BALANCE OF THE STORAGE SYSTEM IN MWH PER DAY. AFTER INCLUDING THE POWER-TO-HEAT CONTRIBUTION, THE RESULTS INDICATE THAT, UNDER THE CURRENT CONTROL STRATEGY AND WITH THE PRESENTLY DEFINED SIZES OF THE SOLAR FIELD AND STORAGE, THE AVAILABLE STORAGE CAPACITY IS INSUFFICIENT TO ACCOMMODATE THE ADDITIONAL CHARGING REQUIREMENTS.

ACKNOWLEDGMENT

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COST-BENEFIT ANALYSIS OF SOLAR-ASSISTED HEAT PUMP HYBRID SYSTEMS IN SOUTH AFRICA

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SUMMARY

Domestic hot water production accounts for a large share of electricity in institutional buildings. Centralised hot water systems with efficient heat pumps (HP) use about half the energy of decentralised electric geysers and can represent up to 25% of a building's total electricity demand. This study investigates solar-assisted HP solutions – Photovoltaic (PV), solar thermal (ST), and PV-thermal (PVT) – to reduce grid electricity consumption, operating costs, and carbon emissions. Simulation optimisation results identify PV-assisted HP as the most cost-effective, delivering the lowest costs, highest returns, and shortest payback. Larger solar fractions and carbon emission reductions can be achieved by combining photovoltaics and solar thermal systems with a marginal impact on the cost of heat. Beyond simulations, the study assesses real-world photovoltaic-thermal assisted heat pump demonstration projects, using monitored performance data to evaluate system efficiency and cost benefits. This work offers valuable insight into the potential of solar energy solutions for hot water production in South Africa.

INTRODUCTION

Integrating solar energy with heat pumps to improve efficiency and reduce costs dates to the 1950s, with research and development intensifying with rising energy costs and ever-growing impetus to reduce carbon emissions (Miglioli *et al.*, 2021). The IEA identifies heat pumps as a key technology for decarbonising heating, particularly when run on low-carbon electricity (IEA, 2022). Recent studies often find photovoltaic assisted heat pumps the lowest-cost option for delivering low-carbon hot water, largely due to the sharp decline in PV costs (Lorenzo *et al.*, 2020). Compared with electric resistance heaters, HPs typically deliver 2–3× more hot water energy per unit of electricity. In institutional settings, retrofitting electric boilers with heat pump water heaters has been shown to cut electricity use and costs. Evidence from South African campus case studies confirms meaningful annual electricity cost savings with simple paybacks of roughly 1.6 years (Tangwe & Kanzumba, 2022). Comparative techno-economic studies across renewable heating technologies in combination with heat pumps remain scarce in South Africa. This study addresses this gap by evaluating various solar technologies integrated with heat pumps.

METHODOLOGY

This study combines simulation-based modelling in Polysun with a comprehensive techno-economic evaluation to assess renewable heat technologies across multiple institutional case studies. Hourly site-specific demand profiles were derived from metered energy data, hot-water temperature, and ambient-condition data to serve as inputs for the simulations. The modelling framework incorporated local municipal time of use tariffs and an optimised HP control strategy that arbitraged thermal energy—charging storage off peak hours and avoiding peak windows while ensuring the hot water demand is met. Operational performance data, including real-time measurements of system variables (temperatures, flow rates, power consumption, irradiance, etc.), were used to evaluate real-world PVT+HP demonstration projects. The techno-economic assessment across all case studies was conducted using key indicators: solar fraction (SF), levelized cost of heat (LCOH), payback period, internal rate of return (IRR), net present value (NPV), annual cost savings, and CO_2 reduction.

RESULTS AND DISCUSSIONS

Across all scenarios, integrating solar technologies with heat pump systems reduced grid electricity consumption for water heating and lowered operating costs relative to the baseline configuration. However, the magnitude of these benefits varied by technology type and the boundary conditions of each building. These differences are influenced by the hot water demand profiles, hot water energy losses, and operational control strategies, as well as local solar resource, time-of-use electricity tariffs, and capital expenditure of solar technologies. Charging the storage tank during off-peak hours and avoiding peak tariff periods amplified the economic benefits across all systems. For PV+HP in particular, alignment between PV generation and off-peak/standard tariff windows further reduce effective heating costs. While ST+HP and PVT+HP configurations benefit primarily through reduced HP usage.

The comparative evaluation based on the system footprint of 300 m² for each configuration, presented in Figure 1, demonstrates apparent differences in techno-economic performance. PV+HP delivers the lowest LCOH (0.68–0.74 R/kWh), the highest IRR (29–31%), and the fastest payback (3–4 years), but the smallest solar fraction (25–35%). PVT+HP achieves the highest solar fraction (50–59%) with a longer payback (12–14 years) and a lower IRR (4–6%). ST+HP LCOH is in line with grid costs with a 42–53% solar fraction, but relatively low IRR (5–9%) and a relatively long payback (10–13 years), with annual cost savings of 32–38% against 23–43% for PV+HP. Further work is required to optimise the combination of solar thermal collectors and size a PV array using the lowest capital costs for CO_2 emission reduction.

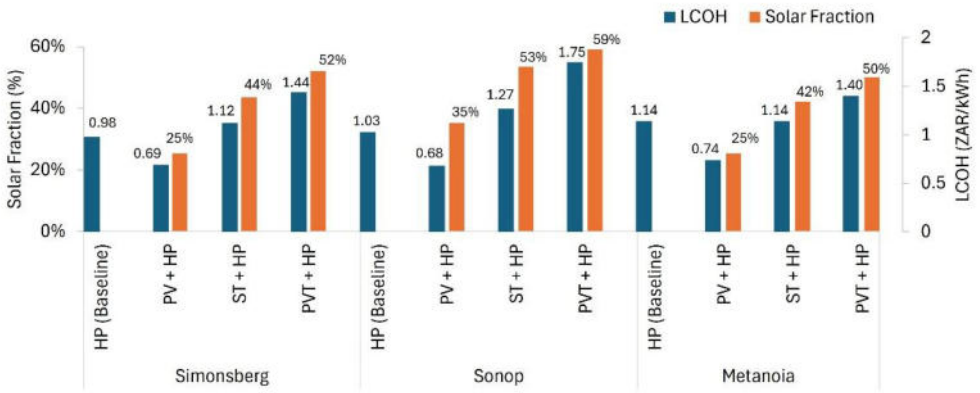


Fig. 1: Comparison of LCOH (ZAR/kWh) and solar fraction excluding surplus electricity benefits (%) – baseline grid and solar-assisted HP systems with 300 m^2 collector arrays at three Stellenbosch University residences

Further analysis will include the sizing optimisation of the collector array, combining PV and ST systems to maximise solar fraction and the techno-economic analysis of installed demonstration PV-Thermal systems and their components in the Cape province.

Ultimately, the selection of the appropriate system configuration should align with the specific priorities of the project and the boundary conditions of the facility. PV+HP is best for projects prioritising rapid payback, high IRR, and low capital cost. ST+HP suits applications focused on maximising renewable heat and further reducing CO_2 emissions, while PVT+HP is ideal where both thermal and electrical outputs are required and space is limited. Sustainability-driven projects aiming for greater carbon savings and higher renewable heat fractions may

find ST or PVT systems better aligned with their objectives, particularly when subsidies for solar thermal energy systems are available.

REFERENCES

Miglioli, A., Aste, N., Del Pero, C., and Leonforte, F., (2021), Photovoltaic-thermal solar-assisted heat pump systems for building applications: Integration and design methods, KeAi Communications Co. Ltd., Beijing, China.

IEA, (2022), World energy outlook special report – The future of heat pumps, International Energy Agency, Paris, France.

Lorenzo, C., Narvarte, L., and Cristóbal, A.B., (2020), A comparative economic feasibility study of photovoltaic heat pump systems for industrial space heating and cooling, Energies, Basel, Switzerland.

Tangwe, S., and Kanzumba, K., (2021), The impact of an air to water heat pump in the residence of a university campus, International Journal of Electrical and Electronic Engineering and Telecommunications, Rowland Heights, USA.

CONFERENCE TOPIC

Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications

ENERGY CONSUMPTION IN LODGES AND GUESTHOUSES IN LESOTHO: INSIGHTS FROM ENERGY AUDITS AND SOLAR WATER HEATING MODELLING

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SUMMARY

This study examines energy consumption in selected lodges and guesthouses in Lesotho through energy audits, aiming to identify major demand drivers, energy management and efficiency opportunities. The hospitality sector is increasingly important to Lesotho's economy; however, limited data exist on how energy is used in the sector and where savings can be achieved. The audits combined walkthrough surveys, utility bill analysis, and end-use assessments of lighting, water heating, space heating/cooling, cooking, and cleaning. Energy use was further analysed using an Excel-based mathematical model. The findings show that water heating and space heating/cooling are the dominant energy consumers. A solar thermal system was proposed for water heating using T-SOL software modelling, with simulation results indicating notable energy savings and reductions in carbon dioxide (CO_2) emissions compared to existing practices. The study highlights both the economic and environmental benefits of sustainable energy solutions in the hospitality sector.

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INTRODUCTION

Lesotho's hospitality sector, which supports a growing tourism industry, faces high energy costs due to reliance on electricity and fossil fuels. Lodges and guesthouses, key service providers, lack data on energy consumption patterns, limiting the identification of efficiency opportunities. Water heating and space heating/cooling dominate energy use, similar to global trends in the hospitality sector. This study conducts energy audits to collect detailed consumption data, which is then used for Excel-based modelling and T-SOL simulations to evaluate energy conservation opportunities. Solar thermal systems present a sustainable option for reducing energy consumption. The study intends to assess the current energy consumption, identify major demand drivers, design appropriate solar thermal systems, and estimate potential energy savings and CO_2 reductions. With daily solar irradiation ranging from 5.5 - 6.5 kWh/m^2/day and growing tourism demand in the country, solar thermal systems offer both economic and environmental benefits for Lesotho's hospitality facilities.

METHODS

Energy audits were conducted at selected lodges and guesthouses across the Maseru district to establish baseline consumption patterns. The audits involved walkthrough surveys, the collection of utility bills, and end-use assessments of lighting, water heating, space heating/cooling, cooking and cleaning. Data collected from the audits was used to develop an Excel-based mathematical model for energy consumption analysis. T-SOL software simulations were then performed to design the appropriate solar thermal system and evaluate its performance, potential energy savings, and assess CO_2 reductions. This methodology enabled the quantification

of end-use consumption, identification of major energy demand drivers, and evaluation of cost-effective interventions tailored to the Lesotho context.

RESULTS AND DISCUSSIONS

The audits revealed that water heating and space heating/cooling were the dominant end-uses, accounting for 40 to 77% of total energy consumption across all the facilities. This highlights the potential for renewable heating and cooling interventions in thermal energy applications. The designed solar thermal systems (mainly for water heating) showed strong performance, with solar fractions of 90 to 99.6%. This corresponds to annual solar energy contributions of 15,072 to 38,506 kWh per facility, leading to significant reductions in electricity use for water heating. Resulting financial savings per collector area were estimated at US $ 75/m^2 to US $ 103/m^2 per year, depending on the facility size and load profile.

From an economic perspective, the systems were viable under an assumed baseline collector area cost of US $ 800/m^2 with a 30% capital subsidy. Investment requirements ranged from US $ 10,480 to US $ 35,632, with payback periods of 9.4 to 12.2 years. The levelized cost of thermal energy was estimated at US $ 0.068/kWh to US $ 0.098/kWh. Moreover, by implementing these solar thermal systems based on collector area, the hospitality facilities can avoid approximately 163.4 kg/m^2 to 225.1 kg/m^2 of CO_2 emissions annually depending on the facility size, underscoring their strong contribution to climate change mitigation and sustainability in the sector. Despite relatively long payback horizons, the systems promise substantial long-term savings and enhanced energy security. Overall, the findings indicate that solar thermal technologies can significantly reduce operating costs and greenhouse gas emissions in Lesotho's hospitality sector, particularly where thermal loads dominate.

CONCLUSIONS AND RECOMMENDATIONS

The study concludes that solar water heating offers a practical pathway for reducing energy costs and carbon emissions in Lesotho's hospitality sector. The audit simulations confirmed that thermal loads dominate the energy use in lodges and guesthouses, making solar thermal systems particularly impactful. Beyond cost savings, such systems enhance energy security, reduce dependence on electricity, and improve the long-term sustainability of the hospitality operations.

It is recommended that future efforts also consider interventions for space heating and cooling, which represent another significant share of energy consumption. Addressing both water and space heating/cooling using renewable energy would provide a more comprehensive pathway to energy efficiency and sector resilience.

REFERENCES

Chamdimba, H.B. and Banda, E.M. (2025) "A review of the adoption of renewable energy technologies by hotels in Malawi," Journal of Energy in Southern Africa, 36(1), pp. 1–11. Available at: https://doi.org/10.17159/2413-3051/2025/v36i1a16047.

Odoi-Yorke, F. et al. (2023) "Technical, financial, and emissions analyses of solar water heating systems for supplying sustainable energy for hotels in Ghana," Solar Compass, 7, p. 100051. Available at: https://doi.org/10.1016/j.solcom.2023.100051.

Ogola, N.O. (2024) Assessment of the Implementation of Energy Conservation Opportunities Arising From Energy Audits; a Study of Four-star and Five-star Hotels in Nairobi Kenya. Thesis. University of Nairobi. Available at: http://erepository.uonbi.ac.ke/handle/11295/167391 (Accessed: September 12, 2025).

CONFERENCE TOPIC

TOWARD A BANKABLE OF THE SOLAR THERMAL TECHNOLOGY ROADMAP AND IMPLEMENTATION PLAN FOR NAMIBIA

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SUMMARY

Namibia's reliance on imported electricity, coupled with rising tariffs and growing energy insecurity, underscores the urgent need for sustainable energy solutions. Solar Water Heaters (SWHs) offer a cost-effective and climate-aligned intervention, particularly given that water heating represents nearly 40% of residential electricity consumption. This study, prepared under the framework of the Namibia Solar Thermal Technology Roadmap (Nam-STTR), provides a comprehensive assessment of the market, policy, financial, and implementation dimensions required to unlock large-scale SWHs deployment in Namibia. The study builds on four complementary deliverables to create a holistic bankable roadmap for scaling SWH deployment. The Market and Policy Review analyse the regulatory, institutional, and supply-demand dynamics shaping the sector, alongside lessons from international best practice such as Tunisia's PROSOL program. The Cost-Benefit Analysis quantifies the financial viability of SWHs across residential, rural LPG-dependent, commercial, and industrial users, highlighting robust returns and resilience under varying tariff scenarios. The Financial Analysis Report explores innovative and inclusive financing mechanisms, including on-bill financing, microfinance, leasing, carbon finance, and Energy Service Company (ESCO) models, identifying their applicability to Namibia's socio-economic context. Finally, the Implementation Plan consolidates these findings into a phased strategy with concrete policy, financial, and institutional interventions to accelerate adoption. The coordinated approach outlined in this work demonstrates the potential of SWHs not only as an energy efficiency measure but as a cornerstone of Namibia's sustainable energy transition and its broader Vision 2030 development goals. Therefore, the main goal of the Southern African Solar Renewable Heating and Cooling Initiative (SOLTRAIN+) project funded by the Austrian Development Agency is to contribute to the transformation of the energy system to a sustainable, affordable and carbon-free system. This will be done by the implementation of Renewable, Heating and Cooling (RHC) systems in the targeted sectors: buildings, industry & commerce, tourism and hospitals, and enable this by a holistic capacity building.

INTRODUCTION

Namibia stands at a decisive moment in its energy transition. The country continues to rely heavily on electricity imports, primarily from South Africa, which exposes it to supply insecurity and tariff volatility. At the same time, domestic electricity demand is steadily increasing, driven by urbanisation, economic growth, and the rising use of electric water heaters (EWHs), which account for nearly 40% of residential energy bills. These pressures not only strain household and business budgets but also undermine national energy security and climate commitments. The Solar Water Heater (SWH) market in Namibia presents a largely untapped opportunity to address these challenges. Despite excellent solar irradiation levels of 2200 to 2400 kWh/m² annually and more than 300 days of sunshine, penetration of SWHs remains extremely low. The analyses demonstrate that SWHs are not only technically and economically feasible, but also critical to achieving Namibia's long-term energy security, climate, and socio-economic development goals. The introduction of bankable financing schemes, coupled with supportive regulation, consumer awareness, and local capacity development, provides a practical pathway toward mass adoption of SWHs, aligning with Namibia's Vision 2030 and its renewable energy targets.

OBJECTIVES

The objective of this study is to provide an evidence-based framework to accelerate the adoption of Solar Water Heaters (SWHs) in Namibia by addressing both technical and financial barriers to deployment. It seeks to build a comprehensive understanding of the current market and policy environment, assess the economic and environmental benefits of SWHs across residential, commercial, industrial, and rural households, and identify financing mechanisms that can make the technology affordable and inclusive.

LITERATURE REVIEW

International experience shows that targeted financing and regulatory frameworks can transform solar thermal markets. Tunisia's PROSOL program and Hawaii's GEM$ on-bill scheme demonstrate how concessional lending, subsidies, and utility-based repayments can drive mass adoption of solar water heating technologies. These models highlight the importance of financial innovation, regulatory support, and consumer confidence in scaling renewable heating and cooling solutions (Yanez-Barnuevo, 2020).

In Namibia, uptake of SWHs has remained extremely limited, with penetration below 2% despite some supportive policy frameworks. This is striking given that electric water heaters account for nearly 40% of household electricity consumption, making the financial case for SWH adoption strong (Ritchie, 2021).

METHODOLOGY

The study applied a multi-pronged approach:

- Market and Policy Review: PESTEL analysis, consumer surveys, and international benchmarking.
- Cost-Benefit Analysis: Financial modelling of four financing models across residential, LPG-dependent rural, commercial, and industrial segments.
- Financial Analysis: Assessment of alternative mechanisms including on-bill financing, leasing, carbon financing, and ESCO models.
- Implementation Plan: Development of phased interventions, financing requirements, stakeholder mapping, and risk assessment.

Data sources included national statistics, tariff records, household surveys, and consultations with key stakeholders (banks, utilities, housing developers, ministries).

RESULTS

- **Economic Viability:** Payback periods range from 2-9 years depending on segment and financing model; IRRs exceed 20% in commercial and industrial markets and 50% for LPG-dependent households.
- **Financial Mechanisms:** On-bill financing and SRF loans are most scalable for urban households; microfinance + subsidies work best for rural LPG users; ESCO and leasing models are attractive for businesses.
- **Implementation Outcomes:** By 2031, Namibia could deploy nearly 19,000 systems in urban households alone, reducing electricity imports, lowering peak demand, and creating local jobs.
- **Policy & Capacity Needs:** Enforcement of building codes, technician training, consumer awareness campaigns, and expanded subsidy pools are critical enablers.

The study concludes that scaling SWHs deployment could achieve multiple national priorities: reducing reliance on imported power, lowering household and business energy costs, cutting greenhouse gas emissions, and creating jobs through local installation and maintenance value chains.

CONCLUSION

Solar water heating represents a financially viable, socially inclusive, and environmentally sustainable pathway for Namibia's energy future. The combined analyses of market conditions, cost-benefit scenarios, financial mechanisms, and implementation strategies confirm that SWHs can deliver short payback periods, significant household and business savings, and measurable reductions in greenhouse gas emissions. More importantly, the study demonstrates that these benefits are attainable across diverse consumer groups, from urban households and rural LPG users to hotels, hospitals, and industrial facilities with high thermal demand. Scaling up SWH adoption will, however, require deliberate and coordinated action. Policy enforcement, particularly through building codes and public housing programs, must be paired with innovative financing tools such as on-bill repayment, microfinance, leasing, and ESCO models to ensure affordability and inclusivity. If implemented as proposed, the roadmap could enable Namibia to meet its ambitious target of 1.5 million m² of installed collector area by 2030.

REFERENCES

Ritchie, M. (2021). *Usage-Based Optimal Energy Control of Residential Water Heaters.* Stellenbosch University. doi: 10.13140/RG.2.2.12747.31524

Yanez-Barnuevo, M. (2020). *On-bill Financing: ExpandingAccess to Energy Efficiency, Clean Energy Adoption, and Electrification for Everyone.* Washington: ACEEE.

CONFERENCE TOPIC

Future District Heating and Cooling Solutions

DRIVING INCLUSION: THE IMPACT OF SOLTRAIN+ GENDER-RESPONSIVE IMPLEMENTATION DESIGN

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SUMMARY

SOLTRAIN+[1] (2023–2026), funded by the Austrian Development Agency, expands renewable energy efforts across five Southern African countries. It integrates industrial applications, energy efficiency, and a targeted 'Women in Energy' work package. The project promotes training, awareness, and technology demonstration in the renewable heating and cooling (RHC) sector. Its Gender & Diversity (G&D) component aims to boost women's participation in a male-dominated field. Activities align with national and regional goals for inclusive, climate-resilient development.[1]

The analysis will focus on evaluating the impact of the G&D implementation phase (2024–2026) and generating recommendations using qualitative data, key performance indicators, and utilising a rapid assessment tool to track progress. Findings will draw from activities like training, mentorship, bursaries, webinars, and gender sessions with results reflecting the integration across work packages, budget use, and collaborative frameworks. These insights will inform lessons learned, growth achieved, and future pathways for inclusive energy action.

INTRODUCTION – BACKGROUND OF SOLTRAIN+ G&D IMPLEMENTATION PLAN

At ISEC 2024 'Increasing the participation of women in the RHC sector through SOLTRAIN+' was presented providing context to the analysis. SOLTRAIN+ contributes to the transformation of energy systems through the implementation of RHC technology in targeted sectors as a solution to bridge regional energy deficits in five SADC countries, Botswana, Namibia, Lesotho, South Africa and Zimbabwe.[1]

The G&D work stream was designed to provide concrete actions and address barriers affecting the participation of women in the sector through the SOLTRAIN+ project. The vision was to build an open, creative, collaborative approach and fun environment that attracts women into working in the sector with a mission to provide a safe and engaging place to grow, test and transform ourselves and each other.[2]

In 2023, analysis findings showed all five countries had gender policies and signed global agreements, yet weak legislation and wage gaps persisted. Women's participation in technical roles remains low (3–37%), hindered by lack of awareness, mentoring, and training. Key solutions in the project included providing equal opportunities, capacity building, and mindset shifts to boost gender equity in the RHC sector. The implementation structure was tiered to create multi-level access to opportunities. Led by the core team, aligned with project partners, implemented by gender managers, and multiplied through a network of 'gender multipliers' the phase intended to reach over 150 women and provide foundations for continued action beyond the SOLTRAIN+ project.

FUNDAMENTALS – MEASURING, ASSESSING AND REVIEWING THE ACTIVITIES

The G&D KPIs were assessed based on the execution of targeted actions, despite operating within a constrained budget for direct gender-specific initiatives. While financial limitations posed challenges, the integration of gender-focused activities across various project workstreams was proactively driven by gender managers and project partners within each participating country. Quantitatively, most targets were met in the first year and surpassed in the second, reflecting strong commitment and adaptability.[3] However, several impactful activities—such as mentorship programs, meet-up sessions, practical "tips and tricks" shared by gender teams, and expert-led gender mainstreaming training—were not originally budgeted and predominantly limited to virtual interactions. However, these unplanned initiatives proved to be instrumental in cultivating soft skills, which emerged as a critical enabler for women seeking to enter and thrive in traditionally male-dominated sectors.

To evaluate the outcomes, data was collected through structured questionnaires and targeted interviews. In addition, an adapted G&D project review tool developed by UN Women[4] will be applied to assess the inclusivity of the workstream. This tool examines key dimensions such as documentation, staffing, leadership representation, participation levels, safety, and economic empowerment.

Qualitative insights, particularly from gender managers and project partners, underscore the value of gender-specific interventions. Early findings reveal that while women are accessing training opportunities, there remains a gap in their ability to fully leverage demonstration funding and the final year of the project could prioritise actions in this direction. Moreover, the data highlights the importance of involving men in gender dialogues to foster inclusive engagement and shared responsibility. Key actions to increase male participation should be taken by the gender team.

Finally, the results point to a broader need for sustained education, awareness-building, and open dialogue around gender and diversity—especially in rural and marginalized communities where systemic barriers persist. These reflections will inform final strategies aimed at deepening impact and ensuring equitable participation across all levels of the SOLTRAIN+ initiative.

LESSONS LEARNED & RECOMMENDATIONS FOR FURTHER ACTIONS

The challenges facing women are multifaceted—ranging from technical and personal to social and emotional barriers—that continue to hinder progress and full participation. While the inclusion of male allies is essential in fostering more equitable environments, invisible boundaries often persist, limiting genuine integration and shared ownership of gender equity efforts. Designing and evaluating impactful initiatives is inherently complex, especially without formal expertise in gender studies, psychology, or inclusive communication. The emotional sensitivity of these topics—often charged with perceptions of favouritism or unfairness—requires careful navigation. Bridging these conversations demands time, empathy, and tailored approaches, as each gap calls for distinct tools and interventions.

Digitalisation presents a promising pathway forward. The integration of technical training, AI-driven solutions, and e-learning platforms can help dismantle structural barriers, particularly in male-dominated sectors. For women working in remote or off-site areas, digital tools such as emergency alert systems, anonymous reporting mechanisms, and virtual mentorship programs can enhance safety and support. However, these solutions face years of development especially in rural SADC where access to basic needs remains.

Despite technological advancements, the human element remains irreplaceable. Emotional support, teamwork, and interpersonal connection are still vital components in addressing the deeper social challenges that technology alone cannot solve. Incorporating clear G&D actions from project inception, with budgets to include additional support in business development, internship programmes or accelerated hands on technical experience are essential.

REFERENCES

1. SOLTRAIN, (2023), Home page, (https://soltrain.org)
2. SOLTRAIN, (2023), Situational Analysis (Internal Project Document)
3. SOLTRAIN, (2024), Project Interim Report, (Internal Project Document)
4. UN Women (2020), UN Women rapid assessment tool to evaluate gender equality and women's empowerment results in humanitarian contexts (https://www.unwomen.org/en/digital-library/publications/2020/05/rapid-assessment-tool-to-evaluate-gewe-results-in-humanitarian-contexts)

CONFERENCE TOPIC

2.03. Just and inclusive mechanism for the energy transition

IMPACT OF TASK 69 IN THE SOUTHERN AFRICAN REGION

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SUMMARY

Southern Africa covers an area 9.85 million km², 406.59 million Inhabitants (5.0% of the world's population and an annual economic output of 779.68 billion US dollars (https://www.worlddata.info/Task 69). This region is currently supported by Southern African Power Pool (SAPP) (12 countries), with a total installed generation capacity of 80 GW, the peak demand in the region is 57 GW, leaving a deficit of available capacity of 48 GW. On the other hand Task 69 in the past 2 year has conducted market survey looking at types of systems in the region, failure modes and effect analysis, possible solutions and recommendation from the design perspective, policy side, standards and training side. The paper gives a summary of the survey of the above from the Southern Africa region and the potential in the region.

INTRODUCTION

For one to assess the impact of research one has to give the brief of the background or status quo, followed up by the new developments in the region in terms of policy in the past 3 years. The paper gives a brief of the results from survey on types of solar thermosyphon systems, failure modes and effects, policies developed across the region in energy efficiency, renewable energy policies, green building standards, minimum energy standards.

METHODOLOGY

The survey involved a questionnaire developed and electronically shared in the countries of the region via email list of previous participants in the Soltrain project and their networks.

RESULTS

Results of list of regional manufacturer, and global suppliers, types of predominant systems being evacuated tube systems followed by flatplate systems. With the majority being direct systems regardless of the challenges related such as fouling due to poor water quality. Modes of failures were highlighted with possible technological and training solutions being covered under the Standards and training subtask. Results of number of training sessions that were undertaken by Soltrain project were enumerated for the past fifteen years.

CONCLUSION

The sustainability plan of initiate such as Soltrain sponsored by Austrian Development Agency has been development such that Roadmaps be taken a step further into Bankability documents that would bring investors for a cumulative market of the Southern Africa region and SubSaharan Africa.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
2.06 Policy frameworks

TECHNO-ECONOMIC ASSESSMENT OF SOLAR WATER HEATING SYSTEMS: A PROOF-OF-CONCEPT FOR LARGE-SCALE DEPLOYMENT IN NAMIBIA

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SUMMARY

The uptake of solar thermal systems in Namibia and the wider Southern African region remains limited. For instance, the implementation of the solar thermal roadmap of Namibia has not been effectively realised. This is primarily due to low market penetration of such systems, coupled with limited technical expertise for their operation and maintenance. Financial constraints, as well as the absence of comprehensive regulation and standardisation frameworks, further hamper large-scale adoption (Fadzlin et al. 2025). The Southern African Solar Thermal Demonstration and Training Initiative (SOLTRAIN+) implemented in Namibia alongside South Africa, Botswana, Lesotho, and Zimbabwe, plays a crucial role in addressing these barriers. Its focus on research, development, and demonstration in the solar heating and cooling sector supports capacity building, while providing tangible examples of real-world solar thermal applications in the Southern African Development Community (SADC) region. In Namibia, the Namibia Energy Institute (NEI)—the national partner of the SOLTRAIN+ project, is conducting a side-by-side comparative study of three widely used solar water heating technologies. This techno-economic evaluation aims to identify the relative performance and cost-effectiveness of each technology under local conditions. The findings will inform evidence-based decision-making on the most suitable solar water heating solutions for different applications and contribute to the implementation of the Solar Thermal Roadmap of Namibia, which is currently under development; while also aligning with the 2007 Cabinet Directive on Solar Water Heaters, which mandates the installation of solar water heating systems in all new public buildings and promotes their adoption in private developments in Namibia.

INTRODUCTION

Renewable heating and cooling are the primary focus of the SOLTRAIN+ project, which aims to build capacity in solar thermal technologies across Southern Africa. This emphasis aligns with the United Nations 2030 agenda for sustainable development, which promotes carbon reduction by the year 2030(UNFCC 2021). To meet thermal energy needs at small scale, thermosiphon systems and photovoltaic-to-heat systems are commonly used. However, to accelerate the adoption of renewable heating and cooling technologies—and to move closer to carbon neutrality—there is a pressing need to prioritise the most cost-effective solutions.

Within this framework, and supported by AEE-INTEC under the SOLTRAIN+ project, the side-by-side solar water heating comparative study investigates the technical performance and cost-effectiveness of selected solar water heating systems under Namibian conditions. The experiment simulates small-scale hot water demand, providing comparative insights that can guide technology selection for broader application.

OBJECTIVES

The objectives of the techno-economic assessment are:

- To compare the techno-economic performance of three widely used solar water heating technologies to identify the most cost-effective and technically viable solutions.
- To provide evidence-based recommendations that will inform the implementation of Namibia's Solar Thermal Roadmap and support compliance with the 2007 Cabinet Directive on Solar Water Heaters.

LITERATURE REVIEW

Most studies examining solar thermal technologies have focused on their performance under simulated laboratory conditions. In particular, the Centre for Renewable and Sustainable Energy Studies (CRSES) at Stellenbosch University conducted a technical evaluation of a flat-plate collector by establishing its efficiency curve in accordance with the DIN EN 12975-2:2006-06 standard. The results demonstrated a strong correlation between the measured data and the established efficiency values for collector input temperatures between 25˚C to 55˚C (Silinga C 2015). In contrast, the NEI's comparative study seeks to assess the performance of the solar water heating systems under stochastic, real-world meteorological conditions rather than simulated laboratory settings. This provides realistic insights into the performance of the test systems.

In a different study in the year 2017, the NEI conducted a comparative study of a flat-plate thermosyphon solar water heating system and a photovoltaic (PV)-to-heat water heating system. Findings indicated that the photovoltaic water heater is convenient to install and operate in contrast to a flat-plate thermosyphon solar water heater due to its simplicity (Shimhanda, Ileka, and Shidhika 2018). This study, however, was based on actual energy consumption patterns of different households, which differed between the two installations. As a result, the findings do not represent a balanced and fair comparison. In addition, the study did not cover the other widely used technology, the thermosiphon water heaters with evacuated tube solar heating systems, which this study will consider.

THE EXPERIMENTAL SET-UP AND OPERATION

Three solar water heating system are installed, and a quantitative approach is used to evaluate their techno-economic performance. Each unit consists of a 200 litres tank and collectors/PV modules with 1.1-1.6 kW equivalent nominal thermal power/kW_P collector installed at 35˚ tilt in the north-facing direction. The three systems are:

System 1: Indirect thermosyphon system with a flat-plate collector;
System 2: Indirect thermosyphon system with evacuated tube heat pipe collector; and
System 3: PV-to-heat system.

Each of the three system's storage tank has a closed-loop network with a coil heat exchanger suspended in a heat accumulator to dissipate heat generated by each system, replicating hot water consumption. The consumption loops of all the three systems are operated at 2-3 bars. Heat meters are installed on both the solar loop (except the PV-to-heat system) and the consumption loop of all three systems, where else an electric meter is installed on the electrical loop of the PV-to-heat system. The heat in the heat accumulator is then dissipated into the surrounding by an air-driven heat pump via a cooling tank to minimise thermal stress on the heat pump. This way, heat generated by the three systems is measured, enabling a comparative techno-economic assessment of the systems.

RESULTS AND DATA ANALYSIS

Data extraction from data logger is continuing. To date, a dataset from for the months April 2025 until August 2025 has been retrieved. The interrogation and interpretation of available data is ongoing. Preliminary results show that a larger dataset, and the characterisation of the systems being compared is required.

CONCLUSION

This comparative study, which is complementary to the comparison study that NEI conducted during the year 2017, will provide insights into the performance of the popular small-scale solar water heating systems in Namibia. Its relevance lies in the proof-of-concept, which is applicable in for applications with hot water demand at temperatures below of 150°C. This project will also feed into the implementation of the bankable solar thermal roadmap, by fostering market confidence in the applicability of these technologies.

REFERENCES

Fadzlin, Wan Afin, M. Hasanuzzaman, S. A. Rahman, and Zafar Said. 2025. 'Solar Thermal Energy Storage: Global Challenges, Innovations, and Future Directions for Renewable Energy Systems'. *Applied Thermal Engineering* 128346. doi:10.1016/j.applthermaleng.2025.128346.

Shimhanda, Senior, Helvi Ileka, and Fenni Shidhika. 2018. 'A Comparative Study of Solar Water Heater and Photovoltaic Water Heater in Windhoek'. in *Renewable Heating and Cooling in Integrated Urban and Industrial Energy Systems*. Graz: AEE-INTEC.

Silinga C. 2015. 'SOLTRAIN II - Solar Water Heating System Test and Demonstration Facility'. Kruger National Park: Kruger.

UNFCC. 2021. *Climate Neutral Now Guidelines for Participation*.

CONFERENCE TOPIC

1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

IS EFFICIENT EFFICIENT? OR: HOW TO DEFINE EFFICIENT DISTRICT HEATING IN A RENEWABLE WORLD?

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SUMMARY

District heating plays an important role to decarbonise heating in Europe. Current research often focusses on the decarbonisation of heat generation in district heating systems. A comprehensive assessment of technical measures in the grid (structure) and the effect on the overall efficiency of district heating systems is missing. Therefore, we conduct a detailed assessment of technical possibilities to increase the efficiency of district heating networks, the economic feasibility as well as barriers for the implementation of the identified measures. The aim of the study is to derive and analyse efficiency criteria for district heating with regard to their future viability, integration into regulatory law and/or the funding framework.

Keywords: District Heating, Energy Efficiency, EED, Life Cycle Assessment

INTRODUCTION

District heating plays an important role in many studies and scenarios for reaching greenhouse gas neutrality in the heating sector. In some cases, it accounts for up to 30 % of the final energy demand for heat supply in buildings in Germany. In scenarios, the focus is often on the absolute amount of energy delivered to costumers through district heating systems and the decarbonisation on the supply side. The efficiency of the network itself is often not assessed in detail and heat losses only considered via flat-rate percentage values. Furthermore, the definition of "efficient district heating" in Article 26 of the Energy Efficiency Directive (EED) does not reflect all relevant effects and has weaknesses in the valuation of efficiency in a renewable world. Both aspects are addressed in this work by

(i) assessing in detail different possibilities to increase the efficiency of district heating networks, and
(ii) comparing different evaluation methods for efficient district heating system, considering many different aspects, which are relevant in a renewable and sustainable world.

The aim of the study is to derive and analyse efficiency criteria for district heating with regard to their future viability, integration into regulatory law and/or the funding framework. This is necessary because district heating (and the entire heating supply) in Germany must be climate-neutral by 2045 at the latest in order to achieve the goals of the Paris Agreement, which the Federal Republic of Germany has ratified. As a residual amount of climate-relevant emissions cannot be avoided in other sectors, the energy sector must become completely climate-neutral. The efficiency criteria for district heating are necessary in order to accompany the process with sensible legislation and funding and to be able to monitor it using various criteria – even in the context of a changing energy system with declining greenhouse gas emissions and primary energy use.

METHODOLOGY

The assessment follows three main steps:

1. Literature review on the status quo: existing efficiency criteria and their application; technical concepts and heat losses in German district heating systems; upstream chains, land and raw material availability of energy sources; contractual arrangements for heat supplies.
2. Assessment of technical aspects with a focus on the networks: supply and return flow temperatures, replacement of existing pipes by new, insulted pipes.
3. Assessment of local and systemic aspects.

In the first step, scientific and grey literature as well as legal and contractual documents are collected and analyzed. The aim is to describe in detail the status quo and barriers for efficiency increases, mainly in Germany but also under consideration of relevant European legislation and literature. In the second step, the technical efficiency is assessed in detail. Technical components of district heating systems, which are relevant for an efficient operation, are identified. Furthermore, the technical components are described regarding relevant aspects for efficiency on the level of single components, but also as part of a whole network. To quantify the effects of technical adjustments, a tool was developed, with which detailed assessments are possible and efficiency gains within the heat network can be calculated. To verify the identified barriers and get a better understanding of their relevance for district heating companies, structured interviews were conducted with representatives of several districting heating companies and first results are challenged in a stakeholder workshop.
In the third step, two exemplary district heating systems are described and modelled in detail. Thereby, the identified possibilities for increasing the energy efficiency in district heating networks and their interaction can be quantified. The effects on the energetic level are then evaluated by applying different methods: total greenhouse gas emissions, total primary energy demand, and resource exergy. For the comparison of the applied methods, relevant aspects for a holistic assessment of district heating are defined and it is assessed, whether and to what extend these aspects are addressed by the different methods.

EXPECTED RESULTS

The applied methodology will lead to a holistic description of the status quo of district heating in Germany. It comprises technical, economic, upstream chains and legal/contractual aspects. The work will focus on aspects connected to the networks itself, the results will help to close a currently existing knowledge gap, as most studies focus on the heat supply of district heating systems. The in-depth assessment of single options for efficiency increases in district heating systems as well as their interaction shows, which measures have a significant effect on increasing the efficiency of district heating systems and which are furthermore economically viable. By comparing different methodologies for a holistic assessment of district heating systems, recommendations for adjusting currently existing efficiency definitions as well as evaluation methods are derived.

CONCLUSION

District heating will play an increasingly important role in the heat supply not only Germany, but also in other European countries. For achieving international, European and national climate goals, the energy efficiency in all parts of the energy system must be increased and the remaining energy must be supplied by renewable energies. For reducing heat losses in district heating systems, many different options exist. However, not all of them are currently implemented due to technical, economic, but also due to legal aspects. The assessment identifies promising options for increasing the energy efficiency of district heating systems with cost efficient measures. Their relevance for the system efficiency and within a holistic assessment considering the demand and supply side as well as upstream chains is shown.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: “Policy Frameworks and Support Mechanisms for Renewable Heating and Cooling”

REVIEW OF INNOVATIVE DEMONSTRATION BUILDINGS FROM LEADING FUNDING PROGRAMS IN AUSTRIA - COMPARATIVE PRESENTATION AND TRENDS

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SUMMARY

The Austrian program City of Tomorrow (2013–2021) provided €79 million to support around 260 R&D projects on climate-neutral urban energy and building solutions, later evolving in 2022 into a new focus on neighborhoods and districts. In parallel, the Smart Cities Demo program (2010–2020) funded urban demonstrators for sustainable city development. Together, these initiatives generated a wide pool of innovative approaches, but heterogeneous monitoring methods and the lack of standardized evaluation hindered comparability and market uptake. The InSite project responds to this challenge by creating a unified evaluation framework, tested on ten pilot projects. It uses standardized key performance indicators across four categories: operation, user comfort, ecology and construction, and costs. Indicators cover aspects such as energy use, CO_2 emissions, thermal and electric storage, comfort parameters, smart readiness, and lifecycle costs. The results are documented in harmonized factsheets and aggregated in an "InSite stamp" for intuitive building comparison.

INTRODUCTION

The transformation toward climate-neutral cities requires innovative solutions that are both technically sound and broadly transferable. Austria has launched several major funding programs to support this goal, resulting in a wide range of demonstration projects and research outcomes. However, the diversity of approaches has made systematic comparison difficult. The InSite project (Monitoring and Evaluation of Innovative Demonstration Buildings) was initiated to establish a standardized evaluation methodology that enables systematic comparison of demonstration projects and accelerates the market introduction of innovative solutions.

Ten demonstration buildings serve as pilot cases where the framework is being applied and refined. Data collection, analysis, and interpretation are harmonized, and the results are prepared in a way that makes them directly usable for planners, decision-makers, and other stakeholders.

THE EVALUATION CONCEPT

The unified assessment framework is built around four main categories:

- **Operation** – Key performance indicators (KPIs) include heating, cooling, and hot water demand (kWh/m²a), CO_2 emissions (kg/m²a), peak load values for heating and cooling (W/m²), and available thermal/electrical storage capacities. Seasonal efficiency and over-dimensioning of systems are also analyzed.

- **User Comfort** – Indoor climate is evaluated through average room temperatures, humidity levels, and the share of time outside comfort ranges. Standard comfort models (PMV/PPD) are excluded due to sensor limitations. User surveys complement the measured data.
- **Ecology & Construction** – This category integrates ecological and design-related factors, such as the Smart Readiness Indicator (SRI), the use of recycled materials, disassemblable connections, and life-cycle indices (OI3, EI10). The Green and Open Space Factor (GFF) accounts for both ecological and functional quality of outdoor areas.
- **Costs** – A life-cycle perspective is applied, covering investment, operation, and maintenance costs, aggregated into specific life-cycle costs per square meter. Due to different project types (new builds, renovations, component upgrades), weighting methods are applied to ensure fair comparison.

Each category contains measurable KPIs that are applied uniformly across all demonstration projects. This structure ensures transparency, comparability, and a balanced view of performance across technical, environmental, and economic dimensions.

All results are documented in standardized factsheets that include both quantitative indicators and contextual project information such as building type, supply concepts, generation efficiencies, and user survey outcomes. To enhance usability, the KPIs are aggregated into an intuitive “InSite stamp”, a visual marker that allows quick comparison between different projects.



Fig. 1: Design representation „InSite stamp“

A public web platform is being developed to provide open access to data, visualizations, and downloadable factsheets. This digital hub will serve as the first point of contact for stakeholders planning new projects and searching for evidence-based benchmarks. A first release of results is expected by the end of 2025.

The InSite framework represents an important step toward harmonized building evaluation in Austria. By linking operation, comfort, ecological performance, and costs within one coherent methodology, it enables evidence-based decision-making for climate-neutral urban development. Beyond its initial pilot phase, the framework has the potential to become a reference standard for evaluating innovative buildings and districts, supporting both policy and practice in the transition to sustainable cities.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

1.16. Transform Cities: Holistic Approaches to Sustainable Urban Energy
2.06. Policy Frameworks and Support Mechanisms for Renewable Heating and Cooling

IMPLEMENTING THE EPBD: WHAT DRIVES TARGET ACHIEVEMENT?

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SUMMARY

The EPBD introduces instruments like Minimum Energy Performance Standards (MEPS) for non-residential buildings and progressive renovation trajectories for residential buildings. While targets are defined, Member States have flexibility in the implementation. We examine for EU-27 how different policy choices affect achieving national renovation plan targets, using the Invert building stock model to test various policy scenarios. Our findings show that progressive renovation targets are hard to meet without regulatory measures. Reducing primary energy factors for electricity and district heating can deliver a significant contribution to the primary energy saving targets.

INTRODUCTION

The EPBD (2024/1275) foresees new policy instruments such as Minimum Energy Performance Standards (MEPS) for non-residential buildings (EPBD, Art 9(1)) and trajectories for progressive building renovation in residential buildings (EPBD, Art 9(2)). Both will affect the roadmaps for building renovation to be outlined in the national building renovation plans. Although the targets are defined, Member States (MS) have a certain degree of freedom in the implementation. So far, it is not well understood how certain policy choices will affect the achievement of energy and climate policy targets.
Following research question guides the analyses in this conference contribution:

- How do different policy choices to implement MEPS in non-residential buildings (Art 9(1)) and the trajectories for progressive building renovation in residential buildings (Art 9 (2)) affect the overall achievement of targets in the national building renovation plan of different Member States and EU-27 as a whole?
- How do MEPS instruments compare with purely economic incentives in the form of CO2-prices?

METHODOLOGY

We adapt the building stock model Invert (Müller, 2015) by updating the building stock data, cost database and policy settings according to Art 9 EPBD provisions. A focus is put on the definition of MEPS-thresholds for non-residential buildings and the identification of worst performance buildings (WPB) for the residential sector. Then, we perform a scenario analysis for selected MS by modifying different policy settings. This leads to a set of scenarios which are defined along three dimensions: (1) implementation of MEPS; (2) level of CO2-prices; (3) evolution of primary energy factors (PEF), driven by the decarbonisation of energy carriers used in the building sector. Finally, we test to which extent the policies under the defined scenarios achieve targets, in particular: (1) primary energy savings according to Art 9, (2) consistency with Zero-Emission-Building standards, (3) renewable energy share target according to the RED. As result indicators we show final and primary energy demand by energy carrier, energy savings in the whole building stock as well as in WPBs and economic indicators.

RESULTS

All scenarios show an increase in heat pumps, district heating and building renovation. However, they differ regarding the extent and speed how gases and liquids are phased out, regarding the role of biomass and regarding the speed and depth of building renovation.
Figure 1 below shows to which extent targets for primary energy savings defined in the EPBD (Art 9(2)) for the residential sector are achieved. The target for 2030 (primary energy savings of 16% compared to 2020) is only achieved in one scenario, which assumes the implementation of MEPS (mandatory for the non-residential sector according to Art 9(1)) also in the residential sector under the assumption that PEF reduce on a pathway in line with achieving climate neutrality of the electricity and district heating sector latest in 2050. None of the other scenarios, even under high CO2-prices, the 2030 targets are achieved. The targets for 2035 (savings of 20-22%) are also achievable without MEPS considering moderate CO2-prices and decreasing PEF.

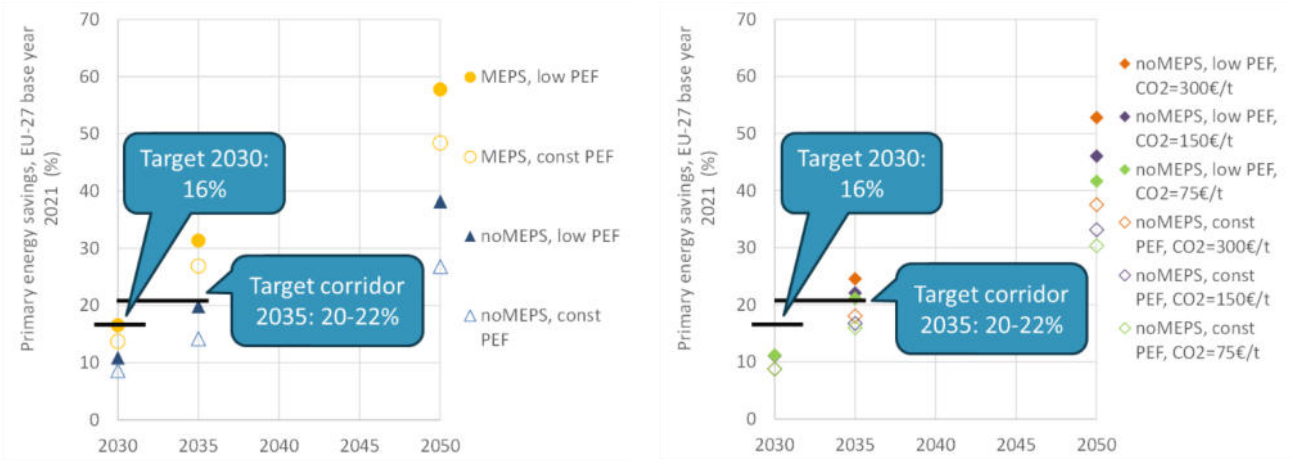


Fig. 1: Primary energy savings in residential buildings, EU-27. 2030 and 2035 targets and their achievement under different policy assumptions

The full conference contribution will also show details on MEPS achievement. Moreover, we will discuss the interaction with other policy instruments within the EPBD and beyond.

CONCLUSIONS

Our results show that the targets for the trajectories of progressive building renovation in the short term are difficult to achieve without regulatory measures such as MEPS. In the mid- to long-term, high-CO2-taxes or comparable incentives may lead to a similar target achievement. The reduction of primary energy factors for electricity and district heating can provide a significant contribution to the target achievement. In the setting of targets beyond 2035 it will be increasingly important to consider the expected decrease in PEFs in order to still maintain an incentive for further improvements of the energy performance of buildings.

REFERENCES

European Parliament and the Council: Directive (EU) 2024/1275 on the energy performance of buildings.
Müller, A., 2015. Energy Demand Assessment for Space Conditioning and Domestic Hot Water: A Case Study for the Austrian Building Stock (PhD-Thesis). Technische Universität Wien, Wien.

CONFERENCE TOPIC

2.06. Policy Frameworks and Support Mechanisms for Renewable Heating and Cooling

FLEXCHECK – A GUIDELINE FOR ESTIMATING INDUSTRIAL FLEXIBILITY POTENTIAL

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SUMMARY

With growing shares of volatile renewable energy generation and rising industrial energy demand, identifying and estimating flexibility potentials in industry is becoming essential. FLEXcheck delivers a structured guideline, supported by two tools – FLEXcel and FLEXscore – that allows companies to assess technical, economic, and practical flexibility with minimal data and expert input. FLEXcel provides a quick estimate via an Excel-based questionnaire, while FLEXscore offers a low-barrier techno-economic analysis using load and production profiles. First applications in Austrian industries demonstrate that even simple estimations can uncover significant flexibility potential and provide guidance for whether more detailed investigations should follow.
Keywords: industrial flexibility, flexibility estimation, software, energy efficiency, peak shaving, load shifting

INTRODUCTION

With the increase in volatile energy production in recent years, and the ever-growing energy demand in industrial sectors, the identification, estimation and utilization of flexibility potentials in industrial energy systems becomes increasingly important. On the one hand flexibility in a production process can be used to reduce or shift the energy demand and therefore does act as grid stabilizing measure. On the other hand, flexibility opens the possibility to decouple energy production and consumption, which in turn creates new business models and can result in a reduction of the overall production costs by e.g. reducing costs for demand charges.
While there are in general several different types of flexibility, the core problem is usually that companies do not fully know which flexibility their processes offer, and how it can be used. With a full analysis of an industrial plant being a tedious and elaborate task, which can e.g. be part of an energy audit, it is very often already sufficient to obtain a first estimate of the flexibility potential without detailed data or deep expert knowledge.
To address exactly this gap the FLEXcheck guideline and alongside the tools FLEXcel and FLEXscore have been developed. The aim of the FLEXcel tool is to provide a simple and easy to use software which can be used to quickly obtain an initial estimate of the flexibility potential of an industrial plant. Based on the individual results from applying the tool the user can then decide whether a further analysis and evaluation of the potential should be considered, or whether small adjustments within the process should be addressed first. As a second step the FLEXscore provides a low-barrier techno-economic analysis tool based on load-profiles to estimate the general economic potential of the identified flexible production units.

FLEXCHECK – DEVELOPED GUIDELINE AND TOOLS

THE GUIDELINE

The FLEXcheck guideline is designed as a stepwise, iterative process that helps companies to systematically identify, classify, and evaluate their flexibility potential. Therefore, the commonly used hierarchy of flexibility classes, beginning with the theoretical and moving through technical, economic, and practical categories until the

realizable potential is used as a baseline for the iterative procedure. At each stage, companies can choose whether a more detailed investigation is worthwhile, thereby avoiding unnecessary effort if little or no flexibility exists. The methodology begins with simple interviews and questionnaires, collecting information about energy consumption, strategic decisions and the boundary conditions. This low-threshold entry point ensures that companies without prior experience can already form a first impression of possible flexibility options. In later stages, the process requires more structured data such as energy load profiles, production schedules, or operational constraints. These inputs enable more refined analyses, ranging from identifying shiftable load blocks to simulating scheduling alternatives or conducting optimization studies.

FLEXCEL – AN EXCEL BASED TOOL FOR FLEXIBILITY ESTIMATION

FLEXcel operationalizes the first stages of the guideline in an accessible tool. By combining a questionnaire with simplified calculations, it allows users to generate a first quantitative estimate of flexibility. To this end, five specific topics have been identified that are addressed within the tool. These focus on strategic decision, energy related aspects, production related aspects, digitalization and generic flexibility measures. For each of the categories an individual score ranging from 0 to 100% of the available flexibility is calculated and presented alongside suggestions for improvements. The individual scores are then combined into one overall flexibility score by using a weighted average. The low data requirements, the ease of use and the accessible interpretability of the score make it suitable for small and medium-sized enterprises as well as larger industrial players.

FLEXSCORE - AN OPTIMIZATION HEURISTIC FOR TECHNO-ECONOMIC ANALYSIS OF ENERGETIC FLEXIBILITY

While FLEXcel provides an initial, largely technical view, FLEXscore extends the methodology towards a techno-economic evaluation. FLEXscore is based on heuristic optimization routines that analyse load and production profiles in order to assess the techno-economic feasibility of exploiting flexibility.
The output of FLEXscore is a quantified estimate of the economic potential that can realistically be achieved by using identified flexibility. This allows companies not only to understand the theoretical flexibility but also whether it can generate tangible financial benefits. The tool thus bridges the gap between theoretical technical potential and actual realizable value.

APPLICATION RESULTS AND CONCLUSION

The FLEXcheck methodology and its associated tools have been applied to three use cases based on Austrian industrial companies from different sectors. Especially the first stage of interviews and questionnaires showed the crucial importance of integrating decision makers, researchers and production and energy managers alike, to achieve reasonable flexibility estimations. The support through tools provided an essential speed up and contributes significantly to the scalability of the approach. In our contribution we provide a detailed presentation of the guideline, and the developed methods used within the tools, combined with experiences from the application for the individual use cases. This aims for providing a complete picture to the estimation of energetic flexibility potential.

REFERENCES

Ausfelder, Florian. (2018). Flexibilitätsoptionen in der Grundstoffindustrie. (DECHEMA e.V.)

Riederer, Bernd and Pfleger-Schopf Kerstin (2025). Leitfaden zur techno-ökonomischen Bewertung von Flexibilitätspotentialen. (Self-Published). http://flexcheck.best-research.eu, *in preparation (to be released October 2025)*

Riederer, Bernd et al. (2025). FLEXcel - An EXCEL-based tool for estimating industrial flexibility and energy efficiency. https://zenodo.org/communities/flexcheck, *in preparation (to be released October 2025)*

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: „IT Solutions and Artificial Intelligence“, „Smart Services and System Operation“, „Flexibility and Stability in Thermal and Electric Grids“

DEVELOPING TRANSITION PATHWAYS FOR DEEP TRANSFORMATIVE CHANGES IN THE BUILDING SECTOR

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SUMMARY

The building sector is among the biggest emitters of CO_2. The significant challenges in its decarbonization make the development of effective strategies for its adaptation crucial for the fulfilment of the Austrian climate protection objectives. We present a comprehensive adaptation strategy for Austrian building stock with a focus on design and land use aspects. The approach consists of an analysis of the current CO_2 emissions, a derivation of detailed intermediate reduction targets for various time horizons and demand purposes and the development of sets of effective adaptation measures. The adaptation measures incorporate the substitution of fossil fuels, renewable sources, energy efficiency improvements, thermal renovation and changes in general conditions in order to identify and highlight an effective spatially differentiated transformation strategy for the of the Austrian building stock. Our analysis aims to produce an overview of quantifiable systemic measures and resulting recommendations to serve as a sound basis for stakeholders and decision makers.

ABSTRACT

In the European Union, the building stock is responsible for 40 % of the primary energy demand and for 37 % of the CO_2 emissions (Gevorgian et al. 2022). Due to the significant investment costs, labor intensity and material demand, adaptations and renovations in the building stock require a long-term effort. Thus, the building stocks substantial share of the total CO_2 emissions and its resource and time intensive adaption makes an efficient strategy for its decarbonization crucial for the fulfilment of the ambitious climate protection objectives. We present a comprehensive analysis and development of an effective adaptation strategy for the building stock through a methodological synthesis of a back casting approach of the future admissible CO_2 emissions and remaining CO_2 budget and the development of sets of measures who ensure to meet the ambitious objectives. We conduct a detailed analysis of the "Austrian Energy Mosaic" to assess the current status of the energy consumption and CO_2 emissions detailed by sectors and demand purposes (Abart-Heriszt 2022). The registration of the current status allows a further derivation of detailed emission budgets for consumer groups and demand purposes which result in the definition of intermediate reduction goals for various future time horizons. Subsequently we develop sets of spatially differentiated measures for the decarbonization of the building stock. The scenario includes the assessment of changes in main framework conditions like climate change induced changes in heating and cooling demand, changing lifestyles and an increasing building stock. Furthermore, the sets of measures will be developed which include the identification of a targeted and impactful thermal renovation strategy, the substitution of fossil fuels and increased production of renewables as well as the application of efficient technologies. The sets of measures will be spatially differentiated under consideration of the local conditions in order to form a sound basis for decision makers. Our analysis aims to produce a quantitative overview of quantifiable systemic measures and resulting recommendations. While addressing Austria, the

results may serve as a reference for other countries and regions with comparable characteristics in terms of the building stock and energy mix.

FIGURES

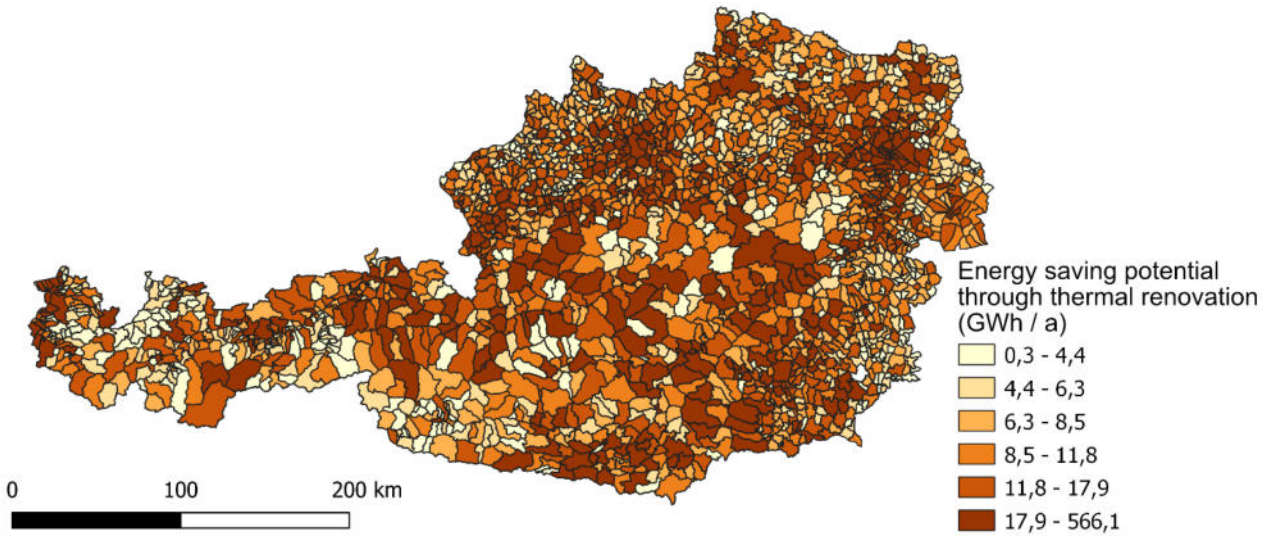


Fig. 1: Energy saving potential through thermal renovation of the residential building stock per municipality in GWh /a

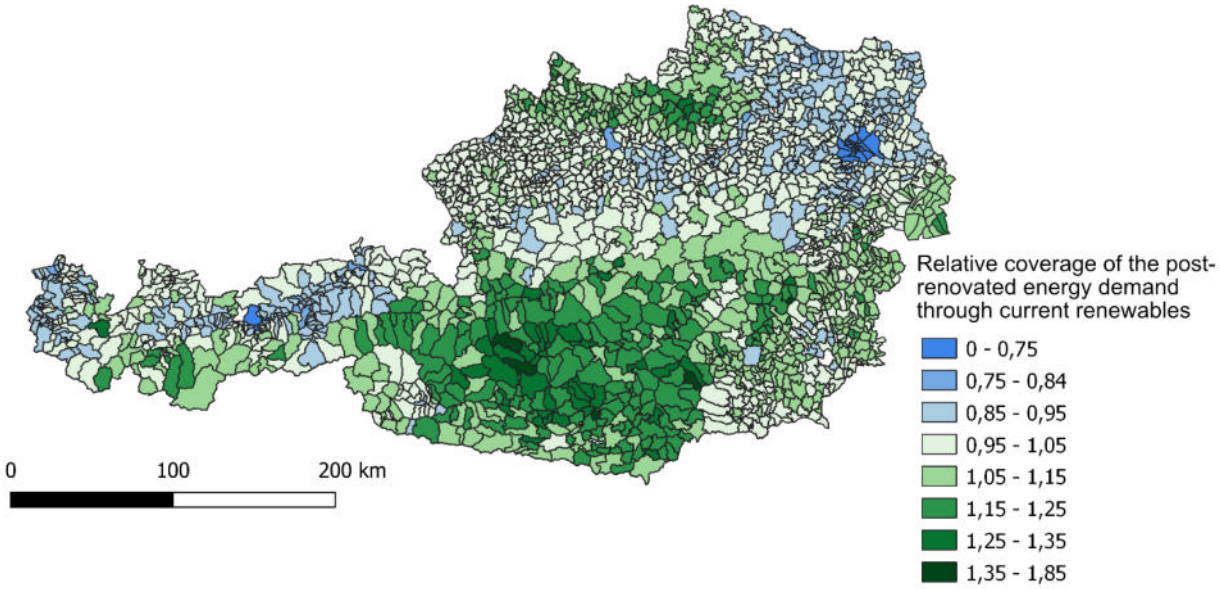


Fig. 2: Relative potential coverage of the post renovated energy demand of the residential building stock through the currently used renewables within the residential stock in 2022 per municipality (1 equals a coverage of 100 %).

Abart-Heriszt, L., (2022), Energiemosaik Austria. Österreichweite Visualisierung von Energieverbrauch und Treibhausgasemissionen auf Gemeindeebene.

Gevorgian et al. (2022), European Building Stock Analysis - A country by country descriptive and comparative analysis of the energy performance of buildings (Eurac Research)

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

- Coupling of Energy Sectors
- Transform Cities: Holistic Approaches to Sustainable Urban Energy
- Spatial Energy Planning with Emphasis on Renewable Energies
- Policy Frameworks and Support Mechanisms for Renewable Heating and Cooling

TOWARDS A SMART CITY DIGITAL TWIN: BIM-BASED 3D VISUALIZATION OF REAL-TIME AND AGGREGATED DISTRICT DATA

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SUMMARY

The management of modern urban districts increasingly requires advanced digital infrastructures that can capture, integrate, and visualize diverse data streams in real time. This paper presents a Smart City Digital Twin architecture designed to integrate federated IFC-based Building Information Models (BIM) with operational data from smart city monitoring systems. The platform enables stakeholders to view both real-time and aggregated datasets in a web-based 3D environment, spatially anchored to district assets. By combining a modular BIM workflow with a targeted monitoring strategy, the system supports continuous situational awareness, operational optimization, and evidence-based decision-making for urban management.
Keywords: Digital Twin, Smart City, BIM, Real-Time Data, IoT, Urban Monitoring, 3D Visualization, IFC.

INTRODUCTION

Digital twins are becoming integral to data-driven governance in urban environments (Batty, 2018), especially in the context of climate-neutral and resilient cities (Ricciardi and Callegari, 2023). While building-scale BIM is common in architecture, engineering, and construction (AEC) workflows, expanding this approach to the district scale requires new methods for handling heterogeneous building models and integrating live operational data. This work addresses the challenge by developing a federated IFC model framework that merges multiple BIM sources from individual buildings and infrastructure assets into a unified district-level digital twin. Unlike monolithic models, this federated approach preserves the autonomy of individual BIM datasets while enabling seamless navigation, querying, and data overlay at the urban scale.

METHODS

The creation of the Smart City Twin begins with the acquisition and preparation of IFC models from various stakeholders, including building owners, facility managers, and municipal infrastructure providers. Each model undergoes semantic enrichment and Level of Detail (LOD) optimization to ensure compatibility with high-performance WebGL-based rendering. The federated IFC integration process aligns the models spatially within a common coordinate system. The resulting composite model forms the spatial backbone for data integration.

The monitoring framework follows a three-layer hierarchy:

1. District Layer: Supervisory data for district-wide energy generation, distribution, and shared utilities, such as central heating and cooling networks, renewable installations, and utility metering systems. This data is collected via BACnet from the district energy central, providing KPIs for generation efficiency, distribution losses, and aggregate resource consumption.
2. Building Layer: Facility-level operational data for HVAC, lighting, water, and energy consumption from building management systems (BMS). BACnet serves as the primary interface for BMS integration, while additional data can be collected via distributed LoRaWAN sensors or through MQTT.

3. Zone Layer (optional): This optional layer enables real-time monitoring of specific rooms or functional areas. LoRaWAN sensors or IoT devices connected via MQTT capture fine-grained parameters such as temperature, humidity, CO_2 levels, and occupancy. These data points are linked to room-level geometry in the IFC model, supporting precise, space-specific analysis.

The three-layer structure allows the Smart City Twin to represent both macro-scale infrastructure performance and micro-scale environmental conditions within a unified federated BIM framework.

RESULTS

The implemented web platform, shown in Figure 1, provides continuous real-time visualization of parameters such as energy performance, temperatures, air quality, etc. Historical datasets can be queried for trend analysis, and thematic filtering allows stakeholders to focus on specific buildings, systems, or time periods. By leveraging a federated IFC structure, the platform maintains the integrity of individual source models while enabling integrated analysis across the district.

CONCLUSION

Our Smart City Twin demonstrates a scalable, interoperable approach to district-level digital twins, based on federated IFC models and standardized protocols (BACnet, LoRaWAN, MQTT). The modular architecture supports incremental integration of buildings and data sources, offering a robust foundation for informed, data-driven urban management.

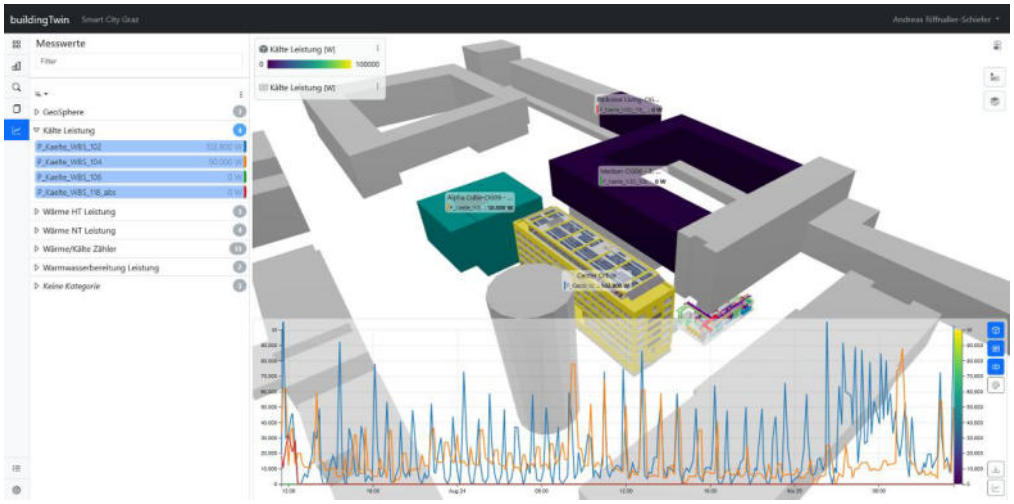


Fig. 1: Web-based visualization of real-time energy performance data on a composite 3D BIM model of an urban district.

REFERENCES

Batty, M. (2018). Digital twins. Environment and Planning B: Urban Analytics and City Science, 45(5), 817-820. https://doi.org/10.1177/2399808318796416

Ricciardi, G., Callegari, G. (2023). Digital Twins for Climate-Neutral and Resilient Cities. State of the Art and Future Development as Tools to Support Urban Decision-Making. In: Arbizzani, E., et al. Technological Imagination in the Green and Digital Transition. CONF.ITECH 2022. The Urban Book Series. Springer, Cham. https://doi.org/10.1007/978-3-031-29515-7_55

CONFERENCE TOPIC

2.02. IT Solutions and Artificial Intelligence; 2.07. Smart Services and System Operation

ON THE IMPACT OF TYPICAL MODEL SIMPLIFICATIONS

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SUMMARY

In many technical fields, highly simplified simulation models are still widely used. What used to be motivated by higher execution speeds is now mostly used because various regulations and standards require it. The German standard VDI 2078 for calculating cooling loads is one such example. The special-purpose models in VDI contain various simplifications that are also frequently found in other building simulation tools. An equation-based simulation environment such as IDA ICE allows for a more realistic consideration of many phenomena, such as variable heat transfer coefficients or the pane-by-pane simulation of windows.

The VDI models have been implemented in the IDA simulation environment and are systematically evaluated and compared with the more detailed native IDA ICE models. For three representative zones, the effects of such simple approaches are presented in terms of studies on heating and cooling performance on the design day and year-round simulations with measured weather data.

INTRODUCTION

A simulation model is always an abstraction of real physical processes, but there are different degrees of simplification in models dealing with the same phenomena. For example, in almost all zone models for building performance simulation, the heat transfer coefficients are fixed values to avoid iteration. The native IDA ICE zone model considers the heat transfer from air to wall dynamically with respect to the temperature difference between the surface, as well as the air and the direction of the heat flow (upwards or downwards).

The VDI models feature a number of simplifications that are also frequently found in other models of conventional simulation tools:

- reduced order wall models
- linearized radiation and convection
- simplified view factors
- diffuse spreading of daylight from windows
- constant g and U values for windows

Until today, the practical impact of model simplifications on design decisions was not studied in great detail. In this paper, the different model approaches are briefly discussed and possible effects on decision-making are shown.

PRELIMINARY RESULTS AND CONCLUSIONS

Figure 1 shows the time curve of heating and cooling power for a test room (VDI 6007-1 validation example 7) with simplified models (IDA VDI) and IDA ICE models compared to the reference results of the VDI "n-c-model". The comparison between VDI n-c-model and IDA VDI show good compliance. The non-linearity of the IDA ICE models is clearly visible compared to the linear progress of the simplified approaches. The average deviation of resulting heating power between VDI n-c-model and IDA VDI is ≈ -2.4% whereas the average difference between n-c-model and IDA ICE is ≈ 35.2%. The mismatch of heating energy between n-c-model (4314 Wh) and IDA VDI (4465 Wh) is ≈ -3.5% and n-c-model compared to IDA ICE (3273 Wh) ≈ 24%.

The paper maps the relative impact of different model simplifications on key design parameters such as cooling load, heating load and energy use for three representative zones in modern construction. The paper shows that the use of better models in the building design stage increases the quality of performance predictions and lowers costs in investment and during operation.

FIGURES

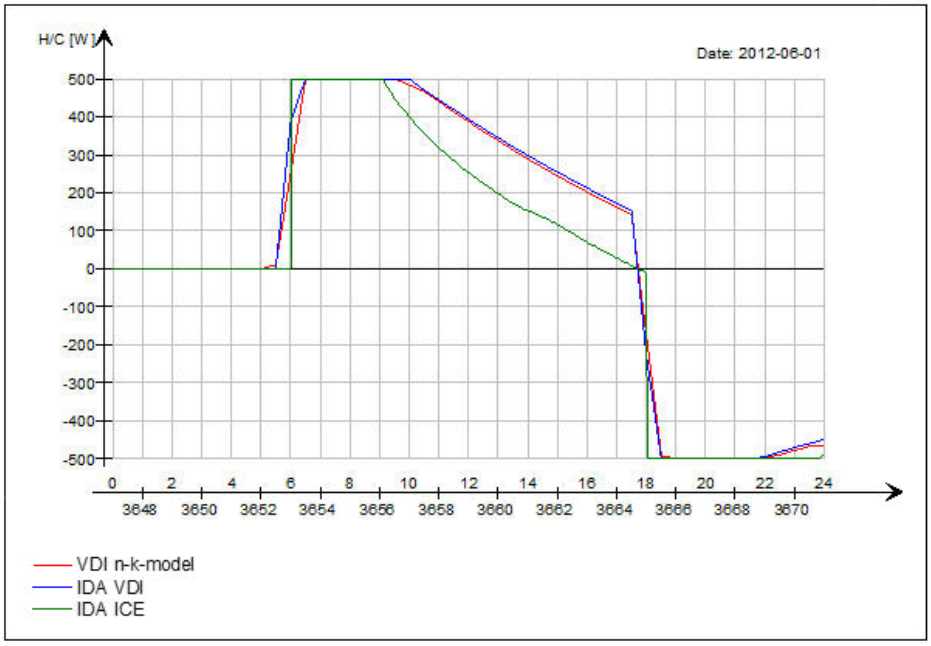


Fig. 1: heating and cooling power for the first day of VDI6007-1 validation example 7

REFERENCES

Verein deutscher Ingenieure e. V. (Hrsg.) (2015-06): VDI 6007 - Calculation of transient thermal response of rooms and buildings - Modelling of rooms (part 1), Modelling of solar radiation (part 3); Beuth Verlag, Berlin

Verein deutscher Ingenieure e. V. (Hrsg.) (2012-03): VDI 6007-2 - Calculation of transient thermal response of rooms and buildings - Modelling of windows; Beuth Verlag, Berlin

Verein deutscher Ingenieure e. V. (Hrsg.) (2015-06): VDI 2078 - Calculation of thermal loads and room temperatures (design cooling load and annual simulation); Beuth Verlag, Berlin

Bring, A.; Sahlin, P. and Vuolle, M. (1999-12): Models for Building Indoor Climate and Energy Simulation, Report of IEA SHC Task 22 (Building Energy Analysis Tools), Subtask B (Model documentation), Version 1.02, International Energy Agency, , Retrieved 2018-07-12

CONFERENCE TOPIC

Policy Frameworks and Support Mechanisms for Renewable Heating and Cooling // IT Solutions

REFERENCE MODELS FOR COMPARING SIMULATION TOOLS TO EVALUATE LOW-CARBON HIGH-COMFORT INTEGRATED LIGHTING

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SUMMARY

Lighting is responsible for 15% of the global electrical energy consumption and 5% of global CO2 emissions. At the same time, the importance of good and sufficient lighting for occupants is well known, both in terms of visual comfort as well as impact on health and wellbeing. Proper design of daylighting and electric lighting is thus of high relevance during the design of a building. To be able to assess the impact of different solutions, planners use simulation tools to evaluate the relevant performance indicators. We present two reference simulation models – one group office and one factory hall – that are used to describe and compare various lighting simulation tools including widely used professional software as well as new research tools. Both models are set up including the required information for integrated daylighting and electric lighting simulation and include full spectral characteristics to also allow evaluating non-visual effects. We provide background information and a detailed description of the models, and present example simulation results. The models provide researchers and professionals a mean to test simulations tools and investigate their applicability for their projects.
Keywords: *Reference models, lighting simulation, tools, spectral simulation, low-carbon high-comfort lighting.*

INTRODUCTION

In recent years, several simulation tools have been expanded or newly developed to perform spectral simulations that allow precise evaluations of non-visual lighting effects (Pierson et al., 2022). This full-spectrum functionality also expands the possibility of simulating solar radiation across the entire wavelength range. This means that such lighting design tools can now be used not only for lighting simulations, but also for energetic and melanopic evaluations (describing non-visual aspects). To help architects and planners choose the right software for their specific project and area of application, we have created a framework for comparing different simulation software. This consists of three parts: (i) a tabular overview of the functions of the individual tools, divided into the core areas of functionality (user group, design phase, algorithms / engines, electric lighting, daylighting, control system, visual and non-visual effects, and support for LCA); (ii) a summary document describing the relevant features of the respective software, and (iii) two reference simulation models to compare the tools in terms of applicability, functionality, and output features. In the present work, we focus on the last point and present the two reference models in detail. A reference model for energy simulations was developed as part of IEA SHC Task 56 (D'Antoni et al., 2018). The "MIT Reference Office" was proposed for lighting simulations to assess façade and electric lighting solutions (Reinhart et al., 2013). Both focus on one area each, but do not cover the broad field of integrative lighting, including energy and LCA considerations. To make this possible, we have created two reference models that cover the two major areas of offices and factories.

REFERENCE MODELS

In order to examine and compare simulation tools for integrative daylight and artificial lighting solutions, we created two comprehensive simulation models: one for a group office and one for a factory hall. For both models we defined the building and room geometry (3d files), full spectral material definition for surfaces and electric

lighting, luminaire and window specifications, control scheme for shading and electric lighting, and LCA-relevant parameters. The full model specification will be made available on an online repository.

Reference Office

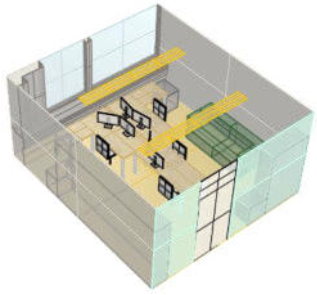


Fig. 1: 3D model of the reference office space.

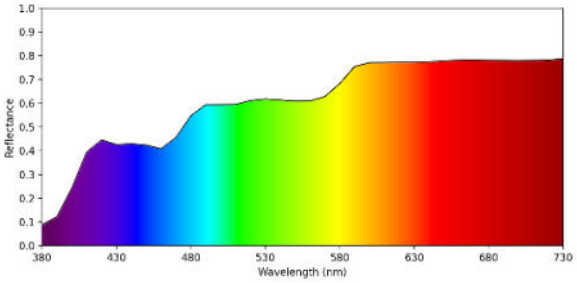


Fig. 2: Spectral reflectance of the wooden desk surface in the reference office (V(λ): 65.58%, M(λ): 53.85%).

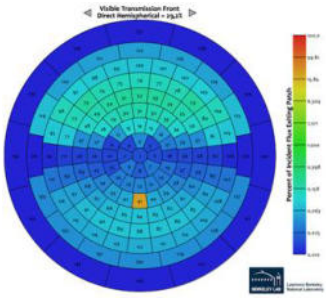


Fig. 3: Example transmission distribution of façade system.

Reference Hall

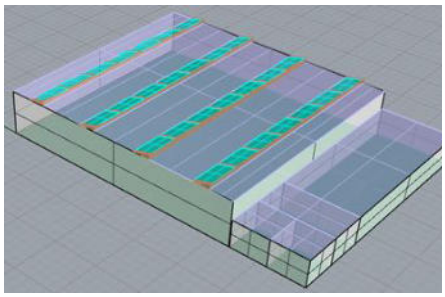


Fig. 4: 3D model of the reference factory hall.

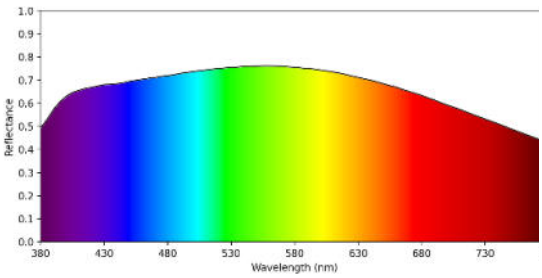


Fig. 5: Spectral transmittance of the rooflight glazing in the reference hall (V(λ): 74.65%, M(λ): 72.54%).

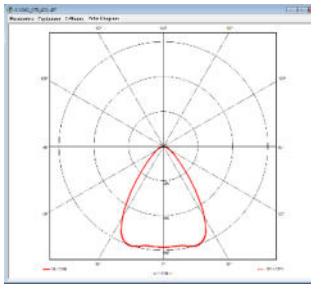


Fig. 6: Luminous intensity distribution of the luminaires in the hall.

EVALUATION AND EXAMPLE SIMULATIONS

We looked at 31 different software tools for lighting simulations and compared their functionality. Some tools focus on electric lighting, others on daylight, and some cover the integration of both well. Using a uniform report template, we report results from the different tools and analyze their pros and cons. We present both the overview of all tools and selected simulations results in detail. The overview and results help users make the right decisions when selecting lighting design tools.

REFERENCES

D'Antoni, M., Geisler-Moroder, D., Bonato, P., et al. (2018). Definition of a reference office building for simulation based evaluation of solar envelope systems. *EuroSun2018 - 12th International Conference on Solar Energy for Buildings and Industry*, pp. 19-28. http://dx.doi.org/10.18086/eurosun2018.06.13

Pierson, C., Aarts, M.P.J., Andersen, M. (2022). Validation of spectral simulation tools in the context of ipRGC-influenced light responses of building occupants. *Journal of Building Performance Simulation*, 16(2), 179–197. https://doi.org/10.1080/19401493.2022.2125582

Reinhart, C., Jakubiec, A., Ibarra, D. (2013). Definition of A Reference Office for Standardized Evaluations of Dynamic Façade and Lighting Technologies. *13th Conference of International Building Performance Simulation Association*. 3645 – 3652. https://doi.org/10.26868/25222708.2013.1029

CONFERENCE TOPIC

2. Support Schemes for Implementation in Buildings, Industry, Districts, Cities and Regions
2.02. IT Solutions and Artificial Intelligence

DEVELOPMENT OF A ROBUST INDEX TO QUANTIFY RESOURCE USE IMPROVEMENTS OF ORGANISATIONS

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SUMMARY

This paper discusses the development of a method that enables organisations to demonstrate progress in reducing resource use for overall activities. The resulting resource efficiency index can be created using this method. It is based on life cycle analyses of organisations (O-LCA) on the one hand and the assessment of the environmental impact of specific measures on the other. The results are presented as a percentage reflecting the cumulative improvements in resource efficiency over a given time period. One main advantage of this approach is that this index is not sensitive to changes in O-LCA methods used, economic fluctuations or structural organisational changes. The method has been tested with data from various industrial companies and can be applied from single production sites to complex organisations. It helps to draw up action plans, to set targets, to predict the effects of measures and to establish continuous improvement (e.g. in the framework of a PDCA cycle). Key words: resource conservation, resource efficiency, life cycle analysis of organisations, O-LCA, impact assessment of measures

INTRODUCTION

The sustainable use of natural resources is essential for the future development of the economy. An important cornerstone in this regard is the measurability of the environmental impact of organisations and their action plans, in order to make improvements in resource efficiency and conservation transparent and comprehensible. There are already various approaches that deal with quantifying resource use and attempt to evaluate it from the perspective of its impact on the environment and/or resource availability. These are usually accounting methods that focus on individual products or projects (e.g. VDI (2016), VDI (2018), ISO 14040/44), or accounting methods that determine environmental impacts at the organisational level (e.g. UNEP (2015), ISO 14072:2024). When targeted action plans are drawn up for an organisation and their impact is to be assessed over time, both approaches are needed. In addition, an assessment method should not be sensitive to changes, for example, in life cycle assessment methods or economic fluctuations.

BACKGROUND OF THE METHOD

The Swiss Energy Agency for the Economy (EnAW) developed a method that quantifies the increase of energy efficiency in companies about 20 years ago. As a result, an overall energy efficiency index was introduced as a metric for the success of improvement measures, showing the increase of energy efficiency over time expressed as a percentage. This energy efficiency index for organisations is now used in Swiss legislation in the context of target agreements with the federal government (Scheidegger, A., et al., (2022)). The process of determining efficiency potential and target values, as well as the structure of the overall energy efficiency index, were adapted for the development of the resource efficiency index. This paper will specify more details on the background and development of the method.

RESOURCE EFFICIENCY INDEX

The resource efficiency index (eq. 1) is based on the life cycle assessment of organisations (O-LCA). Changes in the index over time show how the overall organisation's resource efficiency is developing. Annual fluctuations in the O-LCA result are based, for example, on economic changes or further developments in the life cycle assessment method and are reflected in the numerator and denominator of equation eq. 1. The resource efficiency index is not sensitive to these fluctuations. Fig 1 illustrates how the index can be used to set targets and to monitor interim achievements, e.g. on an annual basis.

(eq. 1)

$$Resource\ efficiency\ index\ (i)[\%] = 100 \times \frac{\sum Points\ (i) + \sum_{k=i0}^{i} Reduction\ in\ Points\ through\ measures\ (k)}{\sum Points\ (i)}$$

"Points" are the result of a fully aggregated life cycle assessment method, e.g. the ecological scarcity method (expressed in UBP) or the European Union's Environmental Footprint method (expressed in EF points).
∑Points (i): Total points of the organisation in the accounting year. i: Index for accounting year (i0: start year)

Reduction measures can include more efficient use of resources in production and other processes (e.g. through product design, waste reduction, renewable energy use), reuse of materials, material substitution, or other measures from the 10R circular economy model (e.g. refurbish, remanufacture).

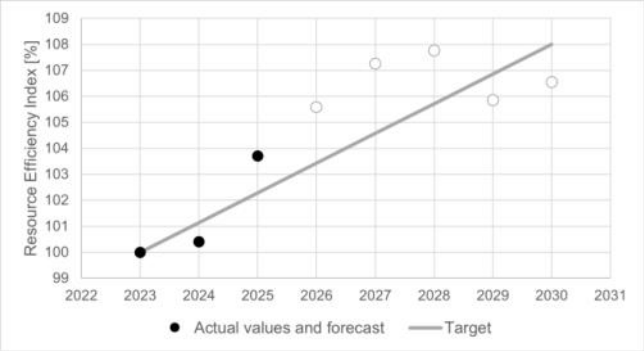


Fig. 1: Exemplary visualisation of a resource efficiency index over time compared to a target line.

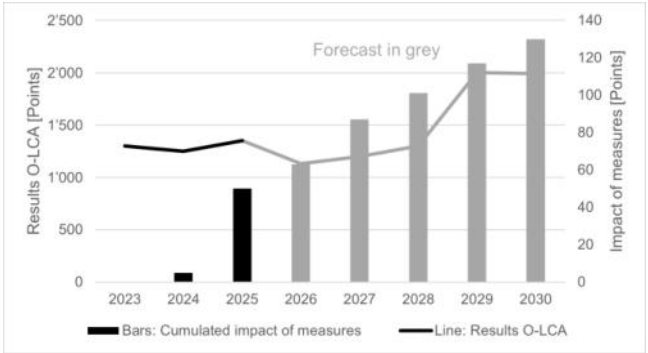


Fig 2: Visualisation of exemplary annual results from organisational life cycle analyses (O-LCA) and the cumulative effects of measures over time

This paper discusses various examples of how the resource efficiency index behaves under varying boundary conditions and parameters.

REFERENCES

VDI, (2016), VDI 4800 Part 1:2016-02 Resource efficiency; Methodological principles and strategies. Beuth Verlag GmbH, Berlin, D.

VDI, (2018), VDI 4800 Part 2:2018-03 Resource efficiency; Evaluation of raw material demand. Beuth Verlag GmbH, Berlin, D

UNEP (2015), United Nations Environment Programme Guidance on Organizational Life Cycle Assessment. https://wedocs.unep.org/20.500.11822/32072.

ISO 14072:2024 Environmental management — Life cycle assessment — Requirements and guidance for organizational life cycle assessment. International Organization for Standardization (ISO), Geneva, Switzerland, 2024. https://www.iso.org/standard/61104.html

Scheidegger, A., et al., (2022), Richtlinie Zielvereinbarungen mit dem Bund zur Steigerung der Energieeffizienz. Bundesamt für Energie BFE, Bern, CH.

CONFERENCE TOPIC

2.04. Life Cycle Assessment / 2.05. Marketing, dissemination and implementation strategies, Cleaner Production, Corporate Sustainability, Circular Economy

ASSESSING CIRCULARITY AND CLIMATE NEUTRALITY AS TWO NEW IMPACT CATEGORIES IN LCA – A CASE STUDY ON HEATING SYSTEMS

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SUMMARY

Climate neutrality and circularity are two main challenges for a sustainable development. They can be addressed by the methodology of dynamic Life Cycle Assessment (dLCA), where GHG emissions, resource & energy demand are calculated and assessed over the entire life time from construction, operation until the end of life management for a service, e.g. heating. The methodology to assess theses new impact categories - Circularity Potential and Climate Neutrality Potential – was developed the IEA Technology Collaboration Program on Electric Vehicles (EVs) and is now also applied to heating systems – wood chips & pellets, heat pump and natural gas. A service is "100% circular and climate neutral", if its whole life cycle - production, operation and end-of-life - uses only reused components, secondary/recycled material, renewable energy and makes no waste and GHG emissions. The comparison of the considered heating systems shows that the heat pump using ambient air and renewable electricity has the highest Climate Neutrality Potential (2.1 E-11 W/m²) while having the lowest GHG emissions (12 g CO_2-eq/kWh), the lowest non-circular mass (7 g/kWh) and the lowest primary energy demand (1.2 kWh/kWh).

GOAL AND SCOPE

The goal is an LCA based comparison of environmental impacts of heating systems by applying a newly developed methodology for assessing Climate Neutrality and Circularity. The considered heating system for 50 kW (technology 2025), 20 years lifetime and 1,600 annual full-load hours are

- Wood chips
- Wood pellets
- Natural gas and
- Heat pump using ambient air and renewable electricity (mix of 15% PV, 25% hydro & 60%wind).

The considered impact categories are

- Greenhouse gas (GHG) emission (g $CO_{2\text{-eq}}$ covering CO_2, CH_4 and N_2O emissions)
- Cumulated Primary Energy demand (CED) (kWh covering fossil, renewable primary energy)
- Climate Neutrality Potential (CNP) (W/m² radiative forcing on top of atmosphere)
- Circularity Potential (CPO) (%) and
- Mass (g of (non-)circular and (non-)renewable mass)

METHODOLOGICAL APPROACH

Based on the definition of a 100% circular and climate neutral energy system a methodology to calculate the Circularity Potential and Climate Neutrality Potential was developed. A service is "100% circular and climate neutral", if its whole life cycle - production, operation and end-of-life - uses only reused components, secondary/recycled material, renewable energy and makes no waste and GHG emissions.

The starting point for calculating the CPO is the Material Circularity Index (MCI) of Ellen MacArthur using the Linear Flow Index ($LFI_{material}$) of materials and the Utility Factor ($UF_{product}$) of products. Additional the fossil primary energy demand and whole life cycle of the products are added in the lifecycle mass balance. The CPO is

between 0% (linear) and 100% (circular) by calculating the total and the circular mass in the total lifetime of the heating systems.
The CNP is based on GHG emissions over the lifetime of the heating system. The CNP is a physical measure of the radiative forcing in W/m² at the top-of-atmosphere taking the reduction of GHG in the atmosphere over the lifetime into account. Theoretically, if the radiative forcing is 0 W/m², the system is 100% climate neutral.

RESULTS

The Figure 1 shows the LCA results – GHG emissions, Climate Neutrality Potential, Primary energy demand and Circularity Potential - over the lifetime of the heating systems and the Table 1 per kWh of useful heat.

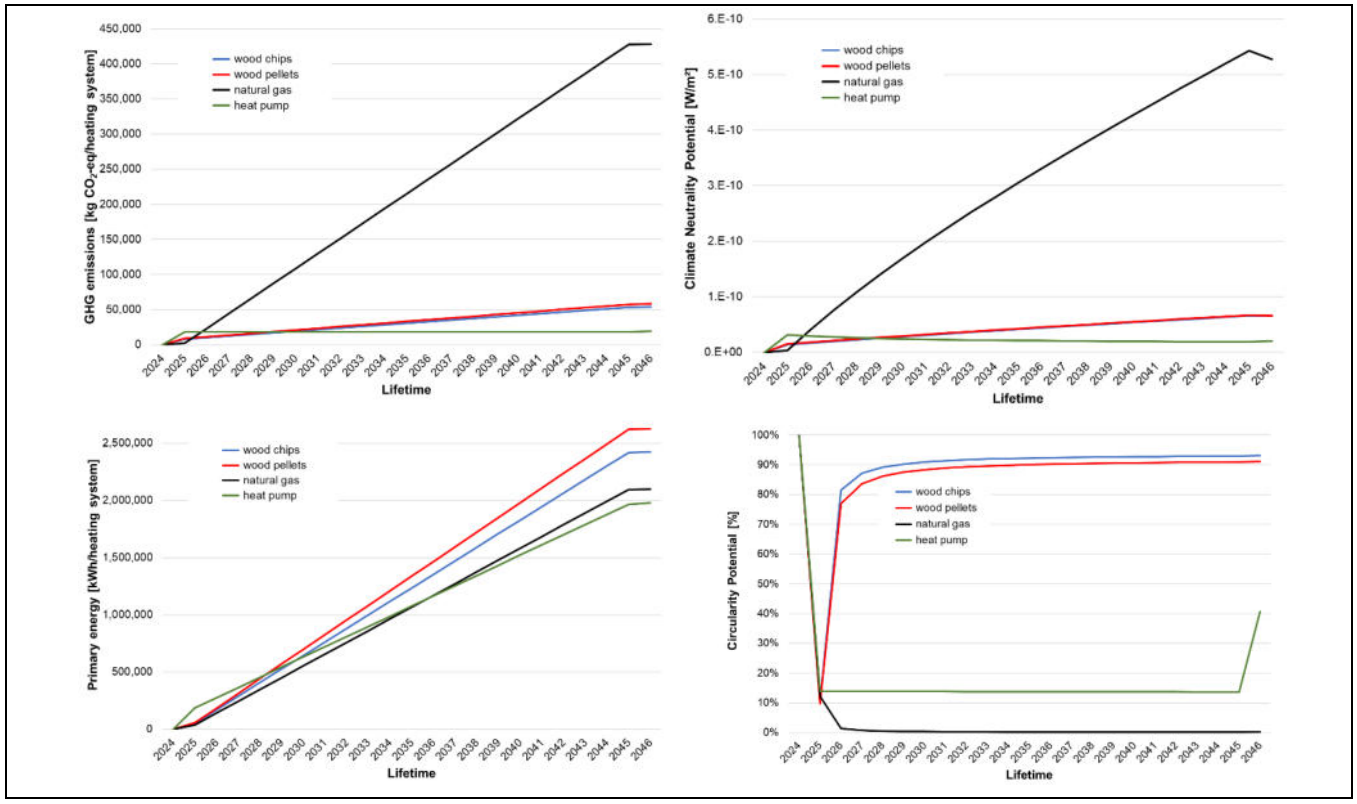


Figure 1: Results over lifetime – GHG emissions, Climate Neutrality Potential, primary energy & Circularity Potential

Table 1: Results per kWh

Impact		Heating system 50 kW			
	per kWh_useful heat	wood chips	wood pellets	natural gas	heat pump
GHG emissions	[g/kWh]	34	36	267	12
Climate Neutrality Potential (CNP)	[W/m²]	6.5E-11	6.6E-11	5.3E-10	2.1E-11
primary energy (CED_tot)	[kWh_primary energy/kWh]	1.5	1.6	1.3	1.2
fossil primary energy (CED_fos)	[kWh_fossil primary energy/kWh]	0.3	0.3	1.3	0.01
mass_tot	[g/kWh]	309	261	85.4	12
mass_non-renewable	[g/kWh]	22	24	85.4	12
mass non-circular	[g/kWh]	22	24	85.2	7
Circularity Potential (CPO)	[%]	93%	91%	0.2%	41%

CONCLUSIONS

The assessment shows that Climate Neutrality Potential and Circularity Potential are two new impact categories not yet covered in LCA. Most of the necessary data are already part of the life cycle inventory. The calculation of the non-circular mass, the renewable-circular mass and the total mass of an energy service are additional

indicators for comparing the circularity of different energy systems, quite similar to the fossil and total primary energy demand. The Climate Neutrality potential gives additional information about the timing of the GHG emissions in the lifecycle and its possible effects on temperature increase. The comparison of the considered heating systems shows that the heat pump using ambient air and renewable electricity has the highest Climate Neutrality Potential (2.1 E-11 W/m²) while having the lowest GHG emissions (12 g CO2-eq/kWh), the lowest non-circular mass (7 g/kWh) and the lowest primary energy demand (1.2 kWh/kWh). The heating system using biomass have the highest Circularity Potential due to the use of renewable biomass, but the total amount of mass is significantly higher than for the heat pump. As expected, the natural gas heating system is the worst in all considered impact categories.

REFERENCES

Jungmeier et al., (2024), Assessing Climate Neutrality and Circularity in LCA – Methodology and Application in a Case Study, Recy & DepoTech 2024, 13. – 15. November 2024, Leoben, Austria
Jungmeier et al., (2025), Assessing the Circularity Potential in LCA as a New Impact Category – A Case Study on Buses, REMADE, April 2025, Washington, USA
Jungmeier et al., (2025): LCA for 100% Climate Neutral Buses – An Approach in IEA HEV Task 46, EVS38 Gothenborg, Sweden, June 15-18, 2025

CONFERENCE TOPIC

Life Cycle Assessment

PLATFORM FOR SPATIAL ENERGY PLANNING: A HARMONIZED APPROACH TO ENERGY DATA MANAGEMENT

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SUMMARY

The heat transition requires municipalities and regions to develop effective strategies based on reliable, comparable, and spatially detailed data. In Austria, decentralized management of energy-related data by federal states leads to inconsistencies in formats and quality standards. In addition, European directives impose stringent obligations for planning, monitoring, and reporting. The Platform for Spatial Energy Planning (PREP) addresses these challenges by creating a harmonized, modular energy information framework across Austria. Building on the outcomes of the GEL-SEP I & II projects, PREP transfers proven methods into long-term governance structures and lays the foundation for integration into the GIS platforms and databases of the federal states.

Keywords: Spatial Energy Planning, Heat Transition, Energy Information Systems, Harmonized Data Models, Public–Public Partnership, Digitalization in Energy Planning

INTRODUCTION

Decarbonizing the heating sector is a core component of the energy transition. Effective strategies require spatially detailed and comparable data on building stock, heat demand, renewable energy potentials, and existing infrastructures. At the same time, the European regulatory framework is becoming increasingly demanding: the Energy Efficiency Directive (EED III), the Energy Performance of Buildings Directive (EPBD), and the Renewable Energy Directive (RED III) introduce new requirements for planning, monitoring, and reporting.
Energy-related datasets are managed in a decentralized way, with the federal states holding primary responsibility. This often results in inconsistencies in formats, methodologies, and quality standards, hindering consistent spatial energy planning and complicating compliance with national and EU obligations.
To address these challenges, the Platform for Spatial Energy Planning (PREP) was launched as a public–public partnership between the national government and the federal states. PREP builds on the results of GREEN ENERGY LAB – Spatial Energy Planning I & II (GEL-SEP I & II), which developed methods and data models for spatial energy planning, including the concept of an “Energy Atlas” or “Heat Atlas.” By transferring these outcomes into permanent structures, PREP establishes the basis for a harmonized energy information system.

CONCEPT AND APPROACH

At the core of PREP lies a georeferenced building model, which provides the essential data foundation for energy planning. Unlike conventional sources such as building registers or energy performance certificates, this model is built by combining and harmonizing diverse datasets. It forms the backbone of a national energy information system that visualizes energy demand, supply, and infrastructure in a unified spatial framework.

Since the availability and quality of data vary across Austria's federal states, implementation must be regionally adapted, while harmonized methods and modular workflows ensure national comparability. The data remain under the stewardship of the federal states, which integrate the structures into their own databases and/or GIS platforms.
The approach is guided by four principles:

- Modular development, enabling step-by-step system growth
- Knowledge transfer from experienced federal states
- Harmonized standards for data models, quality assurance, and protection
- Interoperability through interfaces with national databases

Beyond its technical core, PREP supports applications such as strategy development and monitoring, municipal energy planning (e.g. heating, cooling, mobility), infrastructure development, and information and advisory services. It also serves as an interface for research and funding projects, enabling innovative methods and tools to be tested and reintegrated into planning practice.
The long-term vision is to embed the system into the databases and GIS platforms of the federal states, creating a dynamic framework adaptable to new data sources, evolving regulations, and future applications.

PLANNED ACTIVITIES

In its first year, PREP translates this concept into practice by focusing on the technical and organizational foundations of the platform.
Key activities include:

- Developing a harmonized data model and a quality assurance framework
- Establishing a data protection concept aligned with national and EU requirements
- Creating a prototype georeferenced building model in selected pilot regions
- Defining IT architecture principles and developing interfaces to national databases
- Designing initial GIS-based tools for municipal heating and cooling planning
- Organizing stakeholder workshops to test workflows and build capacity among local planners

These activities form the basis for scaling the platform and expanding functionalities in subsequent phases. The system will also provide a foundation for targeted funding programs and support compliance with new EU obligations.

OUTLOOK

PREP is conceived as a dynamic and expandable platform that fosters close cooperation between federal states and the national government. By harmonizing data, providing shared tools, and engaging key stakeholders, it reduces administrative burdens and enables municipalities to focus on implementation.
Looking ahead, PREP will strengthen the link between governance, research, and practice by acting as an interface for developers and researchers. This ensures that innovative approaches in digitalization and energy planning can be continuously tested, validated, and integrated into real-world planning.

PROJECT REFERENCES

GREEN ENERGY LAB – Spatial Energy Planning I & II – Spatial Energy Planning for the Heat Transition, https://waermeplanung.at/

CONFERENCE TOPIC

2.08 Spatial Energy Planning with Emphasis on Renewable Energies
1.05 Digitalization for Smart, Resilient Energy Systems

PLANNING SUSTAINABLE ENERGY DEVELOPMENT OF LOCAL COMMUNITIES IN SLOVENIA

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SUMMARY

Slovenia's ambitious energy and climate objectives require robust local energy planning, with Local Energy Concepts (LECs) as a central instrument. LECs provide a structured framework for managing local energy use and supply, setting measures for energy efficiency, renewable energy sources, and excess heat, alongside targets, implementation steps, and seven-year monitoring. Analyses of recent LECs reveal significant shortcomings, including limited integration with broader climate, environmental, and social goals, weak spatial analysis, and insufficient stakeholder engagement. These gaps have been addressed through an upgraded methodology based on multi-criteria spatial analysis and GIS tools, tested in demonstration municipalities. The results highlight the importance of stakeholder involvement, realistic target-setting, performance indicators, and actionable strategies. Strengthening data availability and access, methodological rigor, and capacity-building is essential to unlock the broader development potential of sustainable local energy planning.
Keywords: sustainable energy planning, Local Energy Concepts, energy efficiency, renewable energy, multi-criteria spatial analysis

LOCAL ENERGY PLANNING IN SLOVENIA

Slovenia, in line with the European Union, has adopted increasingly ambitious energy, climate, and environmental targets, with energy efficiency (EE) and full-sector decarbonization at the core of its strategy. Achieving these objectives, and ensuring the transition to an energy system with a high share of renewable energy sources (RES) depends strongly on robust planning at the local level. Municipalities and regions therefore play a crucial role as strategic partners alongside national authorities in shaping energy development [1]. A key instrument supporting this process is the municipal energy plan [2], which in Slovenia takes the form of Local Energy Concepts (LEC). High-quality LECs, tailored to the characteristics, potentials, and constraints of individual communities and actively implemented in practice, are essential for meeting the updated National Energy and Climate Plan 2024-2030 (NECP) and Slovenia's Long-Term Climate Strategy to 2050.

The preparation of LECs is regulated by an ordinance [3] and guided by a methodological manual [4]. The ordinance defines a broad scope, requiring analyses of local energy use and supply, emissions, and weaknesses; projections of future energy demand; guidelines for energy supply; assessments of EE opportunities and RES potentials; and measurable targets. Each LEC must also include an action plan, concrete measures, and monitoring indicators to ensure effective implementation and progress tracking.

CURRENT CHALLENGES IN LECS QUALITY

The quality of LECs depends on multiple factors, including data availability and access, methodological rigor, integration of spatial, environmental, and social characteristics, evaluation of RES potentials, and stakeholder

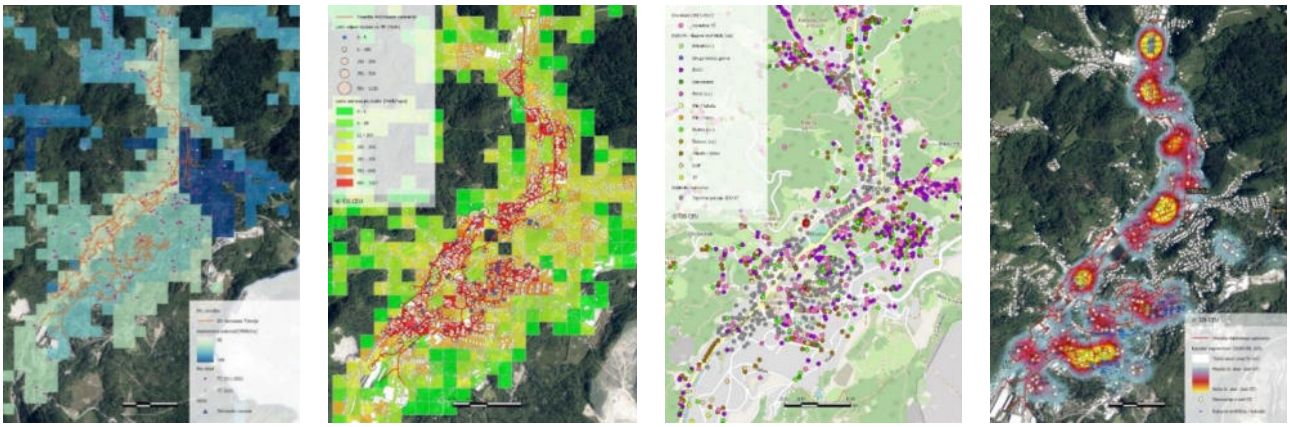
involvement. An assessment conducted within the LIFE Care4Climate (C4C) project evaluated the quality and compliance of most recent LECs with the ordinance, as well as the effectiveness of their implementation through annual reporting. The results [5] indicate that, while the methodology is comprehensive in principle, significant weaknesses arise in practice.

Analyses of energy use and supply often provide a solid foundation, but connections with broader climate, environmental, and social objectives are limited. Rather than adopting a holistic approach, many LECs present fragmented data, which undermines systematic assessment of development opportunities. Spatial aspects are rarely considered, and key geospatial datasets – such as real estate cadastres, public utility infrastructure maps, RES and waste heat sources, and heat maps – are used only to a very limited extent. These gaps are largely due to limited data availability and restricted access, unclear methodologies, limited expertise in spatial analysis, and insufficient supporting studies, particularly for RES potential assessments. Additional challenges include setting realistic targets, defining performance indicators, and preparing sustainable development scenarios, especially with regard to self-sufficiency, EE, energy poverty, and air quality. Weak stakeholder engagement, particularly among actors with significant influence on local energy use and planning, further undermines outcomes. Monitoring of LECs implementation and impacts by the authorities also remains ineffective.

TOWARDS ENHANCED PRACTICES AND SUPPORT

To address these shortcomings, the C4C project introduced an upgraded LEC methodology [6], placing strong emphasis on multi-criteria spatial analysis supported by GIS tools. The approach combines SWOT analysis of local energy systems with active stakeholder engagement, resulting in a long-term structured strategy and action plan for seven years focused on EE, RES, air quality and energy poverty. The methodology was tested in demonstration LECs for three municipalities of different sizes and contexts – Ajdovščina, Trbovlje, and Maribor. Incorporating multi-criteria spatial analyses (see Figure 1) introduced the previously underutilized spatial dimension, enabling more integrated and comprehensive planning for sustainable energy transitions at the local level.

Beyond methodological updates, progress in local energy planning also depends on improving access to geolocated data and strengthening the technical basis for EE and RES measures. High-quality planning relies heavily on spatial analysis and GIS expertise, which requires targeted training for LEC developers. Establishing capacity-building programs for stakeholders is considered essential to ensure effective planning and implementation of sustainable energy measures, and such programs were introduced in 2025.



a) b) c) d)

Fig. 1: Examples of geospatial layers for multi-criteria spatial analysis of local energy use and supply: a) geothermal potential (geo-probes); b) heat map and public utility infrastructure; c) small combustion plants; d) cultural heritage and building renovation potential [7].

REFERENCES

[1] Gerritsen, M., (2023), Energy and strategic energy planning. In K. Van Asche, R. Beunen, & M. Duineveld (Eds.), Elgar Encyclopedia in Urban and Regional Planning and Design (pp. 133-135), Edward Elgar Publishing Limited.
[2] Wretling V., Gunnarsson-Östling U., Hörnberg C., Balfors B., (2018), Strategic municipal energy planning in Sweden – Examining current energy planning practice and its influence on comprehensive planning, Energy Policy 113, 688-700.
[3] Ordinance on the Methodology and Mandatory Content of Local Energy Concepts. Official Gazette of the Republic of Slovenia, 56/2016.
[4] Manual for the Preparation of Local Energy Concepts, (2016). Available at: https://www.energetika-portal.si/podrocja/energetika/lokalni-energetski-koncept/metodologija-lek.
[5] Čižman, J., Staničić, D., Stegnar, G., Merše, S. (2023), Challenges in the Preparation and Implementation of Local Energy Concepts. In J. Nered, K. Polajnar Horvat, & M. Goluža (Eds.), Green Transition at the Regional Level / Zeleni prehod na regionalni ravni (pp. 27-38) Založba ZRC, Regional Development Series 9, Ljubljana.
[6] Čižman, J., Staničić, D. Upgrading the LEC Methodology and Improving Implementation. Report for the LIFE CARE4CLIMATE Project – Activity C4.3: Upgrading Local Energy Concepts, (2023). Available at: https://www.care4climate.si/_files/2155/Nadgradnja_metodologije_LEK_v1_5.pdf.
[7] LEC - Municipality of Trbovlje, (2024). Available at: https://www.trbovlje.si/DownloadFile?id=751189.

CONFERENCE TOPIC

2.08. Spatial Energy Planning with Emphasis on Renewable Energies

IMPACT OF BUILDING DESIGN VARIABLES ON DEMAND RESPONSE CAPABILITY CONSIDERING LOCAL GRID PROFILES

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SUMMARY

The increasing share of volatile renewable energy sources poses challenges for balancing supply and demand in electrical power systems. Demand response is considered a promising strategy to address this issue, creating a need for evaluation metrics that assess grid participants' ability to effectively apply demand response strategies. Many existing approaches rely on indicators focusing on energy costs, efficiency, or greenhouse gas emissions, while the impact on local grid stress remains insufficiently captured [1]. To address this gap, this work introduces the *Grid Stress Index* (GSI), an evaluation metric that enables benchmarking of a building's contribution to local grid stress. We demonstrate the method in a simplified simulation environment with a direct-optimization based building control strategy that implements load shifting by preheating. A use case illustrates how the metric can evaluate the impact of building design parameters to load shifting potential. Results show that the GSI captures the beneficial effects of increased insulation and thermal mass, while also revealing non-additive interactions between these parameters. Furthermore, the location awareness of the metric is demonstrated by evaluating the installation of photovoltaic systems in two distinct grid contexts, revealing how the same intervention can either mitigate or increase local grid stress.

Keywords: Demand response, key performance indicators, spatial energy planning, Grid Stress Index.

GRID STRESS INDEX

The GSI is defined in Equation (1) as a whole-building indicator for assessing a building's impact on grid load.

$$GSI = \frac{1}{E}\int_T w(t)p(t)dt \tag{1}$$

Here, p denotes the consumed power, w is a weight (penalty) function and $E = \int_{t\in T}|p(t)|dt$ represents the total gross energy flow. The evaluation period T is set to one day in this work due to optimization constraints, though it can be modified as needed.

The resulting metric has several useful properties:

- Normalization: $-1 \leq GSI \leq 1$. This enables comparisons across buildings of different sizes and allows the independent assessment of energy efficiency and grid friendliness.
- Interpretability: $GSI = \pm 1$ occurs only when a grid participant exchanges power exclusively during periods of peak grid stress. A value of GSI = 1 indicates that the building reinforces the peak (e.g., consumption during a demand peak), whereas GSI = −1 indicates that it counteracts the peak (e.g., export during a demand peak). Intermediate cases fall between these two extremes.

PROOF-OF-CONCEPT SIMULATION ENVIRONMENT

To test the method, a proof-of-concept simulation environment was implemented in Python, modeling a building with a cuboid geometry. The model includes heat loss through the thermal envelope, a simplified heat storage at internal surfaces and an idealized heating system. Heating strategies are optimized using PSO to minimize a cost function, which accounts for total energy consumption weighted by an assumed load profile as well as a penalty for deviations outside the thermal comfort range of 20–24°C.

A typical result for a heating strategy is depicted in Fig. 1.

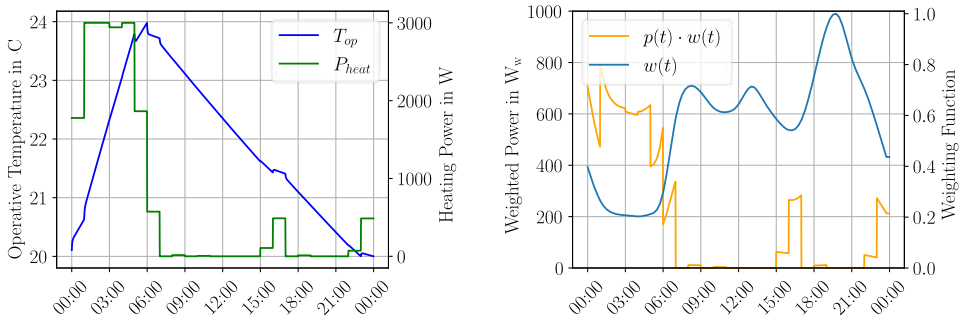


Fig. 1: Left – the heating strategy keeps the operative temperature between 20°C and 24°C. Right – the weighted energy consumption is minimized.

ANALYZING IMPACT OF BUILDING DESIGN VARIABLES

In the preliminary simulations, the optimization results in load shifting through preheating. This effect is influenced by the insulation layer thickness (d_{ins}) and the effective heat storage capacity of the internal surfaces, represented by an equivalent thickness (d_{sto}). Varying these building design parameters produces the results shown in Fig. 2.

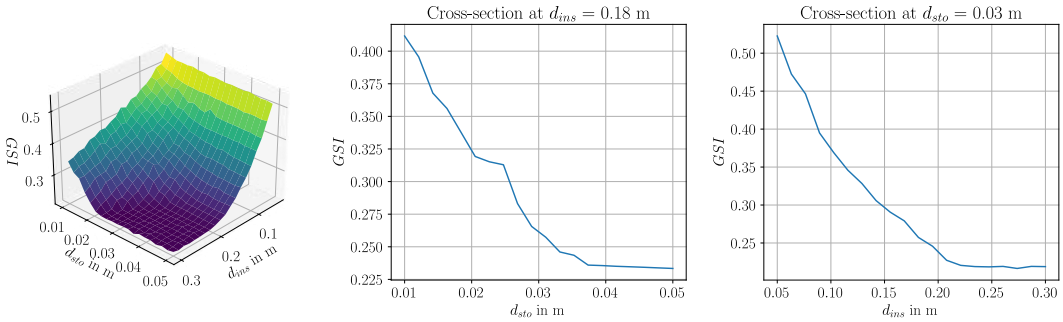


Fig. 2: Varying two design variables allows the analysis of combined effects. Increasing insulation thickness or storage capacity reduces the GSI.

Considering the upward curvature of the GSI surface with increasing values of d_{ins} and d_{sto} in Fig. 2 indicates a redundancy or saturation effect between the two parameters. Physically, the saturation occurs because heating demand is progressively moved into the low-weight nighttime period, reducing the remaining potential for further improvement.

CONCLUSIONS

The results are consistent with expectations: Increasing the insulation layer thickness improves heat retention within the building, while higher thermal capacity reduces the rate of temperature drop for a given heat loss. The ability to identify combined effects between building design parameters offers a tool for optimizing building design with respect to demand response potential.

REFERENCES

[1] Li, H., Wang, Z., Hong, T., Piette, M.A., 2021. "Energy flexibility of residential buildings: A systematic review of characterization and quantification methods and applications". Advances in Applied Energy 3, 100054. https://doi.org/10.1016/j.adapen.2021.100054

CONFERENCE TOPIC

Spatial Energy Planning with Emphasis on Renewable Energies

FROM LOCAL TO NATIONAL: HEATING SECTOR PROJECTIONS FROM MUNICIPAL HEAT PLANS IN GERMANY TOWARDS 2045

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SUMMARY

The transition to climate-neutral heating in Germany is largely driven by local-level action. Following the introduction of the National Heat Planning Act (Wärmeplanungsgesetz, WPG 2023), all municipalities are obliged to develop local heat plans with the aim of achieving a climate-neutral heat supply by 2045. This paper presents initial findings from a systematic analysis of the heat plans of over 220 municipalities and introduces a machine learning-based approach to scaling up local strategies and deriving a national bottom-up scenario for the heating transition. A comparative analysis of this bottom-up scenario against conventional, top-down energy system studies reveals significant differences and implications for the future governance of the heating transition.
Key-words: Municipal heat planning, district heating, decentral heating, efficiency, scenarios, policymaking

INTRODUCTION AND RESEARCH QUESTIONS

Municipal heat planning has emerged as a cornerstone of organising the heating transition. It informs investment decisions regarding heating technologies and infrastructure development. Under the WPG 2023, large cities (municipalities with more than 100,000 inhabitants) are obliged to submit their heat plans by mid-2026, while all other municipalities have until mid-2028. As of August 2025, around half of Germany's municipalities had started the planning process and plans had been completed for approximately 500 municipalities (KWW 2025).

Our contribution addresses the following research questions:

- What insights can be derived from evaluating the first wave of municipal heat plans, and what strategies are municipalities pursuing? Are there already significant differences evident?
- What methodological approaches are suitable for scaling up municipal heat plans in order to create a national-level scenario, while taking into account the wide range of conditions and potentials for the local heat transition in different municipalities?
- How does this national, bottom-up scenario (derived from municipal heating transition strategies and extrapolated to create a German heating transition scenario) compare with the top-down scenarios from cross-sectoral energy system studies, which aim to optimise the overall energy system?

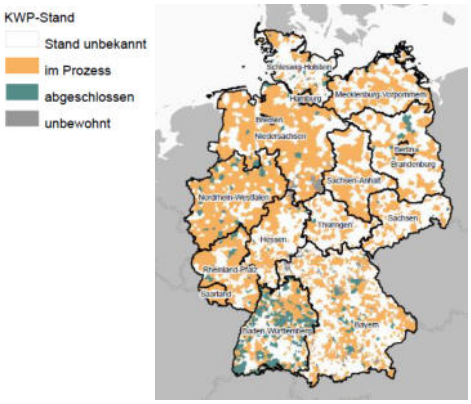


Fig. 1: Overview of the implementation of municipal heat planning in Germany (as of June 2025) (KWW 2025)

METHODOLOGY

The analysis draws on a sample of heat plans of 220 municipalities. Baden-Württemberg was the first federal state to introduce mandatory municipal heat planning in 2020. Consequently, a significant number of heat plans are available from this federal state. To avoid bias resulting from Baden-Württemberg, only 20% of the available plans from that state were included, whereas all publicly accessible plans from the other 15 federal states were considered.

The key indicators analysed include the current distribution of energy carriers and heating technologies, important drivers such as the refurbishment rate and energy efficiency levels the municipality is striving for, and the projected distribution of energy carriers and heating technologies for 2045 – the target year for climate neutrality. Machine learning regression methods were used to derive a national heat transition strategy from various local strategies, scaling up the local approaches to create a national strategy. Various regressors were tested for predictive performance and robustness checks were conducted. The upscaled scenario was then compared to top-down national energy scenarios in terms of structure, ambition and system design.

RESULTS

The analysis reveals a high heterogeneity in local heat strategies. Significant differences exist between municipalities in their assumptions and targets for energy savings, the role of district heating networks (including the energy mix used for heat production) and the contribution of different decentralised heating technologies, such as heat pumps. These differences are partially influenced by municipality size, existing infrastructure and regional conditions.

For national upscaling, we identify the most relevant features (e.g. population size, heating degree days and renewable energy potential) for accurate extrapolation, as well as the machine learning regressors that deliver the most robust results (Gradient Boosting and Random Forest regressors). Comparing the national, bottom-up scenario with national, top-down scenarios reveals structural discrepancies, particularly concerning the assumed levels of decentralisation and the role of district heating. We discuss possible reasons of these discrepancies and their implications for national policymaking.

The paper presents results from the project KOMpare (Making municipal heating planning in Germany transparent and comparable), which is funded by the Federal Ministry for Economic Affairs and Energy.

REFERENCES

WPG (2023), Wärmeplanungsgesetz vom 20. Dezember 2023 (BGBl. 2023 I Nr. 394)

KWW (Kompetenzzentrum Kommunale Wärmewende), Overview of the implementation of municipal heat planning in Germany, https://experience.arcgis.com/experience/480e8a1a8b564fd8b389e30aaeae4565 (as of June 2025)

CONFERENCE TOPIC

The abstract refers to the Conference Topics “Support Schemes for Implementation in Buildings, Industry, Districts, Cities and Regions” and “Spatial Energy Planning with Emphasis on Renewable Energies”.

ECONOMIC VIABILITY OF DECENTRALIZED VS. COLLECTIVE HEAT SUPPLY IN URBAN BLOCKS: A CASE STUDY FROM VIENNA

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e7 energy innovation & engineering

ABSTRACT

INTRODUCTION AND OBJECTIVES

Vienna has committed itself to achieving climate neutrality by 2040. A central challenge on this path lies in decarbonising the city's building stock, particularly in neighbourhoods dominated by single- and two-family houses as well as row houses. These settlement structures, often outside the existing district heating network, are currently supplied almost exclusively with fossil gas through decentralised boilers. At the same time, they represent around 45,000 residential units within the city and therefore play a decisive role in the achievement of municipal climate targets.

The presented study analyses the technical, economic and organisational feasibility of transitioning these structures to renewable heat supply. It was commissioned by UIV Urban Innovation Vienna GmbH within the framework of the municipal initiative "100 Projekte Raus aus Gas". The aim was to identify both individual and collective decarbonisation options and to assess their replicability for the wider urban context. A special focus is placed on legal and planning frameworks, in particular where heritage protection and conservation zones restrict the application of conventional renovation measures.

METHODOLOGY AND ANALYTICAL FRAMEWORK

The study followed a mixed-method approach, combining data collection and site analysis, energy demand and system modelling, scenario development, economic evaluation, and organisational models. Building documentation, energy certificates, existing heating systems, user structures, and ownership constellations were collected and complemented by site visits and stakeholder interviews.

Energy demand was assessed using building typologies, reference energy certificates and TABULA datasets. Scenarios were developed for individual and collective solutions with renewable technologies such as heat pumps, biomass boilers and cold local heating networks (anergy systems). Economic evaluation included lifecycle cost analysis, sensitivity checks with higher electricity prices, and the role of subsidies. Organisational models ranged from individual building solutions to energy communities and third-party operated service models.

CASE STUDIES

Three test cases were selected to reflect different typologies of settlement, ownership and legal frameworks.

- **Castlegasse, 1210 Vienna:** A row housing settlement of 51 units, built in the 1970s with additions in the 2000s, owned by GESIBA. Current supply is decentralised gas boilers. The homogeneity of the stock and single ownership create favourable conditions for collective solutions such as an anergy network or centralised low-temperature heat pumps.

- **Cottage Quarter, 1190 Vienna:** A historical neighbourhood with around 640 buildings, mostly private ownership, many located within a conservation zone. Gas remains the dominant heat source. A pilot block was analysed under the constraints of heritage protection. Challenges include fragmented ownership, strict regulatory requirements, and high transaction costs for collective solutions.
- **Mauerbachstraße, 1140 Vienna:** A small-scale row house complex with six units, owned by ÖSW. The buildings are unsanitary and rely on decentralised gas boilers. The limited scale and renovation needs pose economic challenges, but the site offers potential for compact solutions.

Together, these three cases provide insights across different governance and technical contexts: from single-owner social housing to fragmented private ownership under strict heritage protection.

TECHNICAL SOLUTIONS

Two main categories of solutions were assessed.

- Individual solutions include air- or ground-source heat pumps, biomass boilers, or hybrid systems. These maximise autonomy and reduce organisational complexity but often entail higher costs per dwelling and limited efficiency at scale.
- Collective solutions include low-temperature heat networks (anergy systems) or small-scale district heating with central renewable sources. These exploit economies of scale, reduce technical space requirements, and allow heating and cooling. They require coordinated investment and governance structures.

For conservation zones, refurbishment measures were considered that do not compromise historic appearance, such as internal insulation, insulating renders, and window retrofits. Solar technologies were also assessed, with examples demonstrating feasible integration even under strict guidelines.

ECONOMIC AND ORGANISATIONAL ASPECTS

Cost comparison shows that individual solutions often appear more favourable, particularly without subsidies. Collective solutions become competitive when subsidies for infrastructure and renovation are available, transaction costs are minimised, and long-term operating costs are considered.

In neighbourhoods with a single institutional owner, collective solutions are straightforward as decisions can be made centrally. In fragmented private ownership, as in the Cottage Quarter, transaction costs and legal hurdles often outweigh technical advantages.

Three implementation models were identified: individual supply, collective self-supply, and service provider models. Each entails different trade-offs in terms of autonomy, upfront investment, and long-term contractual dependence.

KEY FINDINGS AND RECOMMENDATIONS

There is no one-size-fits-all solution for decarbonising Vienna’s single-family-dominated settlements. Different ownership, heritage, and economic conditions require tailored approaches.

- Technical: standardised design approaches for collective networks, provision of public space for infrastructure, simplified permitting for renewable systems in conservation zones.
- Financial: expanded subsidies covering infrastructure and transaction costs, adapted funding instruments for fragmented ownership.
- Organisational: stronger role of initiators such as municipalities and housing associations, use of cooperative models and energy communities, integrated legal frameworks to enable shared ownership.
- Social acceptance: enhanced communication with residents, raising awareness of long-term benefits, fostering trust through pilot projects and transparent governance.

CONCLUSION

Decarbonising single-family-dominated settlement structures is essential yet complex. Technical solutions are feasible, but success depends heavily on economic frameworks, ownership structures and regulatory conditions. The three test cases illustrate the spectrum of opportunities and barriers, from collective solutions under single ownership to the complexities of fragmented, heritage-protected areas. Scaling up requires supportive policy, funding and institutional innovation.

The results are relevant beyond the studied cases and provide a blueprint for similar urban neighbourhoods across Vienna, supporting the city's ambition to achieve climate neutrality by 2040.

The study was commissioned by the City of Vienna through UIV Urban Innovation Vienna GmbH.

600 °C CLASS MIDDLE-HIGH TEMPERATURE PACKED-BED LATENT HEAT STORAGE UNIT WITH ALUMINIUM-SILICON BASED PCM PELLETS ~ PERFORMANCE ANALYSIS OF BENCH-SCALE APPARATUS ~

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SUMMARY

Thermal energy storage (TES) is essential to stabilize renewable energy supply, and latent heat storage offers high energy density and conductivity for high-temperature applications. This study examines Al-Si alloy-based microencapsulated phase change material (MEPCM, melting point 577 °C) fabricated into composite pellets. A bench-scale packed bed thermal energy storage system containing 75 kg of Al-Si@α-Al_2O_3 pellets was tested under discharging conditions at 300 °C. Results showed temperature stagnation from latent heat storage, sustaining heat exchange performance. A validated numerical model confirmed predictive accuracy, demonstrating MEPCM's potential for efficient high-temperature TES applications.

INTRODUCTION

A stable supply of renewable energy necessitates advanced storage technologies to mitigate output fluctuations. Thermal energy storage (TES) represents a promising approach, with latent heat storage offering superior energy density and thermal conductivity, particularly for high-temperature applications. This study focuses on the development of Al-Si alloy based microencapsulated phase change material (MEPCM) with a melting temperature of 577 ºC, fabricated into composite pellets. The MEPCM pellets enable direct contact heat exchange analogous to sensible heat storage[1]. Here, the heat storage and release characteristics of a bench-scale packed bed latent heat storage system charged with Al-Si MEPCM pellets were systematically evaluated.

METHODOLOGY

Fig. 1 shows an image and a schematic diagram of the bench-scale packed-bed latent heat storage experimental apparatus. The 75 kg of cylindrical Al-Si@α-Al_2O_3 MEPCM pellets (with a diameter of 10 mm) are packed into a thermal storage box measuring 39 cm by 40 cm. An air heater flows through the packed bed to exchange thermal energy directly. Thermocouples measure the temperature in the packed bed at 10 cm intervals along the height. In discharging mode, the airflow temperature was 300 °C.

RESULTS AND DISCUSSION

Fig. 2 shows the temperature profiles during discharging mode. The results show temperature stagnation due to latent heat in the MEPCM. In this study, the effects of the flow rate and temperature of air on the heat transfer rate are investigated. In addition, an experimentally validated numerical model has been developed and verified.

CONCLUSION

In this study, we prepared 75 kg of microcapsule particles containing an Al-Si alloy core and an α-Al_2O_3 shell for use as a latent heat storage material. We evaluated the heat storage and discharge performance of a direct heat exchange system in a bench-scale packed bed containing high-temperature latent heat storage pellets, with the MEPCM acting as the main component. The results show that temperature stagnation due to latent heat in the MEPCM. In this study, the effects of the flow rate and temperature of air on the heat transfer rate are investigated. In addition, an experimentally validated numerical model has been developed and verified.

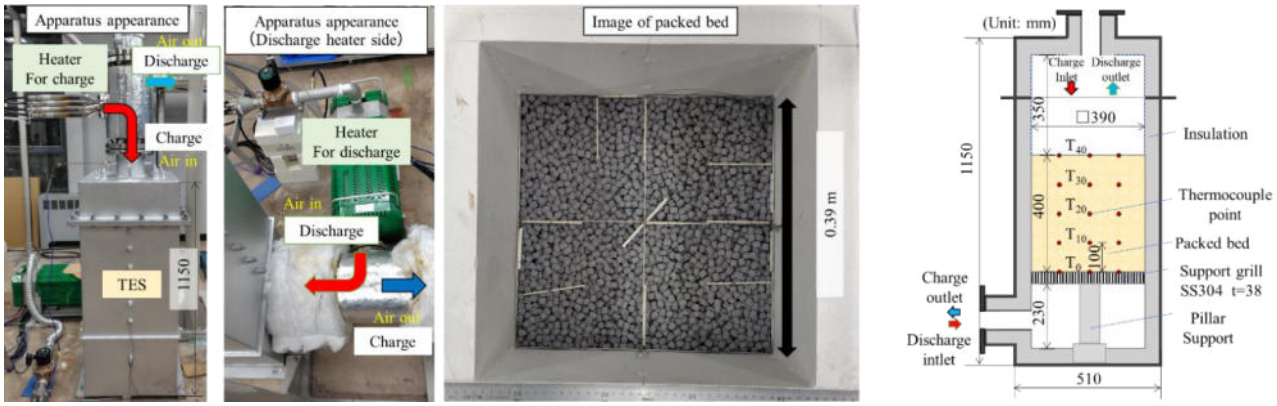


Fig. 1: Image and a schematic diagram of the bench-scale packed-bed latent heat storage experimental apparatus

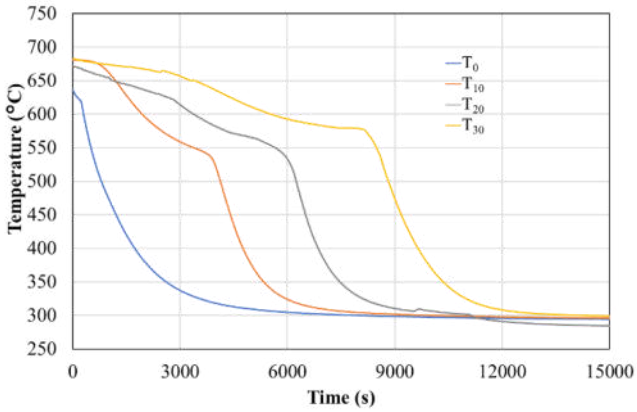


Fig. 2: The temperature profiles during discharging mode

ACKNOWLEDGEMENT

This paper is based on results obtained from a project, JPNP20005, subsidized by the New Energy and Industrial Technology Development Organization (NEDO).

REFERENCES

[1] H. Koide et al., Energy, 238, Part C, (2022), 121746

CONFERENCE TOPIC

1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

POTENTIAL AND CHALLENGES OF AI TOOLS IN THE PROCESS OF INDUSTRIAL DECARBONISATION STRATEGY DEVELOPMENT AND EVALUATION

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SUMMARY

The transformation of industrial energy systems to climate neutrality is essential but hindered by data gaps, system complexity, and economic feasibility. Digital technologies, particularly generative AI, provide new approaches to address these challenges. Large Language Models (LLMs) can reconstruct incomplete datasets, interpret interdependencies, forecast demand, and facilitate the integration of renewable energy sources. In this study, AI tools were tested in a standardised use case across the main phases of an energy audit. Results show that GenAI can enhance optimisation and bridge data gaps, but its effectiveness depends on data quality, prompting skills, and user expertise. Industrial complexity, limited domain-specific training, and issues of trust and social acceptance remain barriers.
Keywords: Industrial decarbonisation, audit, renewables, GenAI, Large Language Models, user acceptance

INTRODUCTION AND PROBLEM DEFINITION

There is no alternative to the transformation of industrial energy supply into a sustainable and climate-neutral system. The challenges of this transition are obvious. In 2019, only 14% of global primary energy consumption was covered by renewable sources[6], and in the EU-27 this share was also just under 18% in 2021[7]. The industrial sector represents about a quarter of this demand in the European region and this is also mainly fossil-based[7]. The focus is on reducing fossil demand through efficiency measures and integrating renewable technologies, many long-established and others still emerging. Yet measures must be technically, ecologically, and economically viable. Identifying and evaluating options is challenging and requires a thorough assessment of the status quo. High-resolution, long-term data are rarely available, and costly measurements often block progress.

This is where digital technologies (big data analytics, AI, IoT, digital twins,e tc.) offer potential. They can optimise energy use, increase efficiency, enable real-time monitoring, support renewable integration, and ensure transparent tracking, though challenges of feasibility, compatibility, data governance, and workforce skills remain. (K. Aviso, 2025)

Among these digital technologies, generative Artificial Intelligence (GenAI) promises to be the emerging transformative tool. It refers to algorithms capable of creating new content (code, text, images) based on patterns learned from huge datasets. At the core of many GenAI applications are Large Language Models (LLMs), trained on large-scale language data sets and can generate context-sensitive outputs, interpret unstructured data, and provide advanced decision support. In the context of industrial energy systems, LLMs and related models promise to assist in structuring and interpreting incomplete datasets, automating documentation, supporting scenario analysis, and even translating technical results into accessible formats for diverse stakeholders. This shall open new opportunities to address the identified challenges currently slowing down decarbonisation processes. But whoever has used GenAI tools is raising questions of transparency, reliability, and user acceptance.

6 IEA, "World Energy Balances: Overview," Paris, License: CC BY 4.0, 2021. [Online]. Available at: https://www.iea.org/reports/world-energy-balances-overview

7 Eurostat, 2023

METHODOLOGY

To evaluate the potential of artificial intelligence in supporting industrial decarbonisation, we tested several state-of-the-art AI tools currently available on the market, including ChatGPT[8], Mistral[9], and ClaudeAI[10]. A standardised use case was developed reflecting challenges across all industrial sectors as basis for evaluation. The methodology followed three levels of detail (quick&dirty, detailed, high-resolution) along the main phases of an energy audit, beginning with the generation of reliable datasets from rudimentary information typically supplied by industry. It then addressed the interpretation of data and the identification of interdependencies between production processes, building energy demand, and mobility requirements. Finally, the optimisation phase focused on evaluating efficiency measures and integrating renewable technologies at both process and system levels. This approach enabled a comparative screening of the tools with respect to robustness, usability, and their contribution to accelerating the decarbonisation of industrial energy systems. Regarding user acceptance and the social impact on GenAI use, a survey as well interviews and workshops with affected companies and employees was conducted. This work was done within the project "Sustainable Working AI" funded by *Zukunftsfond Steiermark*[11] and a master thesis conducted.

RESULTS AND OUTLOOK

AI, and in particular generative AI, offers promising opportunities along the audit and decarbonisation system design process. Above all, it is a nice "buddy" to discuss ideas, explain ongoing developments and by this reducing the barriers and user's concerns. However, in detail, it involves reconstructing incomplete datasets, interpreting large datasets, detecting inefficiencies, forecasting energy demand, and optimising the integration of renewable technologies. It can further support scenario analysis, ease documentation, and translate technical results into accessible and understandable formats. However, its effectiveness is highly dependent on the availability and quality of underlying data, its training, the precision of prompting, and, crucially, the expertise of users to interpret and validate the outputs. Industrial energy systems are inherently complex, and most current GenAI tools are not yet specifically trained on such domain-specific challenges. This limits the reliability and robustness of their solutions. Concerns about data security, safety, and computational requirements pose additional barriers to adoption (A.Windmann, 2024). Beyond technical aspects, the social impact of AI adoption must not be underestimated. User acceptance can vary across all levels and departments of an industrial company. While some experts in administration and management increasingly recognise GenAI as a supportive tool, concerns are equally present among engineering, operational, and production staff. These may include fears of job displacement, reduced autonomy in decision-making, or a lack of trust in "black-box" solutions. Such reservations can slow down or even block implementation. Addressing them through transparency, co-design, and competence development is therefore just as essential as solving the technical challenges. While actually the evaluated GenAI tools can significantly enhance optimisation capabilities and bridge information gaps, it cannot replace the domain knowledge and engineering judgment needed to design viable decarbonisation strategies. Future developments must therefore focus on transparent, standardised, and user-centric frameworks, embedding explainable AI methods and tailoring models more closely to industrial contexts. Only through this combination of technical advancement, human expertise, and trust-building can AI evolve from a supportive tool into a cornerstone for climate-neutral industrial energy systems.

8 https://openai.com/de-DE/index/chatgpt/?utm_source=chatgpt.com

9 https://mistral.ai/?utm_source=chatgpt.com

10 https://www.eesel.ai/blog/claude-vs-mistral?utm_source=chatgpt.com

11 https://www.zukunftsfonds.steiermark.at/

REFERENCES

Kathleen B. Aviso, (2025), Decarbonizing the chemical industry through digital technologies, Digital Chemical Engineering, Volume 16, 2025, 100250, ISSN 2772-5081, https://doi.org/10.1016/j.dche.2025.100250.
A. Windmann, P. Wittenberg, M. Schieseck and O. Niggemann, "Artificial Intelligence in Industry 4.0 (2024): A Review of Integration Challenges for Industrial Systems," 2024 IEEE 22nd International Conference on Industrial Informatics (INDIN), Beijing, China, 2024, pp. 1-8, doi: 10.1109/INDIN58382.2024.10774364.

CONFERENCE TOPIC

2.02. IT Solutions and Artificial Intelligence
1.05. Digitalization for Smart, Resilient Energy Systems

FROM PROCESS CHAINS TO HUB-LEVEL OPTIMISATION: ASSESSING INDUSTRIAL FLEXIBILITY FOR HUBS FOR CIRCULARITY

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SUMMARY

The Austrian industrial sector, responsible for a substantial share of national emissions and energy demand, plays a key role in achieving climate neutrality by 2040. As renewable energy integration advances, demand-side flexibility (DSF) becomes essential to balance supply and demand. This research has the aim to explore how industrial flexibility potentials can be identified and facilitated within Hubs for Circularity (H4Cs). By linking the optimised flexibility potentials of industrial process chains with hub-level requirements, the approach aims to enhance renewable integration, reduce system costs, and strengthen regional and supra-regional resilience. The findings will provide actionable insights for industry and policymakers to foster sustainable, resource-efficient energy systems.

INTRODUCTION

In 2021, the Austrian industrial sector was responsible for 26 million tonnes of CO_2eq, around 34% of national greenhouse gas emissions, and consumed 88 TWh of final energy, corresponding to 28% of total final energy demand [1,2]. Austria aims to achieve climate neutrality by 2040, supported by national legislation targeting a complete shift to renewable energy sources [3,4]. However, the increasing share of variable renewable energy in electricity markets poses challenges for system stability, which makes flexibility a key requirement. Flexibility - defined as the ability of generators, loads, or storage facilities to adapt their operation in response to system needs - e.g. as an option to balance fluctuations between energy supply and demand.

According to the Austrian Energy Agency, balancing requirements will reach approximately 4 TWh by 2030, based on current daily and weekly demand patterns [3]. Existing storage capacities, such as pumped hydro storage plants with 2.7 TWh capacity, cannot fully cover this demand, and a gap of about 1.3 TWh remains. By 2040, electrification of multiple sectors may increase, therefore the overall demand and renewable supply will increase by an additional 50 TWh [4], with a substantial share attributed to industry. This development implies an urgent need for DSF. Improving industrial flexibility will therefore be essential to ensure system resilience and efficient renewable integration.

H4Cs provide an ideal environment to investigate industrial DSF potentials. As integrated circular ecosystems, H4Cs connect industrial zones with urban or rural areas, through industrial-urban-rural symbiosis. This collaborative framework supports regional climate neutrality, resource efficiency, resilience, and energy sovereignty, while highlighting the strategic role of industrial DSF in future energy systems.

METHODOLOGY

The aim of the ongoing research is to estimate the energy-based industrial symbiosis potentials within H4Cs, by analysing, modelling, and optimising the flexibility potentials of industrial energy systems and the associated energy flows with a high symbiosis potential within hub networks.

PROCESS-RESOLVED SYNTHETIC LOAD PROFILES

The methodological framework builds upon the software tool "Ganymed", developed at the Chair of Energy Network Technology at the Technical University of Leoben, which enables a time-resolved simulation of process chains in energy-intensive industries. Using a bottom-up approach, the process chain is modelled on a process-by-process basis. The process aggregation then leads to an overall synthetic electrical and thermal load profile. [7] The profile accuracy depends on the resolution of the individual process profiles, which are currently being refined to better capture process-specific dynamics and to integrate climate neutrality technologies such as electrification options or hydrogen-based processes. In order to reach the pathways to climate neutrality and embedding flexibility, this extension of Ganymed allows a deeper systematic analyse of actual industrial process chains and future process chain developments by considering the integration of future technologies, like heat pumps or electrolysers.

INDUSTRIAL FLEXIBILITY POTENTIALS FOR HUBS FOR CIRCULARITY

Furthermore, the industrial flexibility potentials by applying different flexibility strategies will be analysed within the simulated chains, such as load shifting, partial load operation, and fuel switch in a mathematical optimisation model.

Building on the process-resolved synthetic load profiles and the identified flexibility options, a mathematical optimisation models utilises the industrial flexibility through demand response to optimise the overall energy and resource supply and consumption within an H4C. The program is built as an energy hub model [8], where both industrial processes and energy production units are represented as interconnected energy nodes with temporal constraints. The core objective is to determine which optimisation approach is best suitable for optimising flexibility while ensuring compatibility with the dynamic needs of H4Cs. By embedding process-level flexibility into a network optimisation environment, the approach provides a systematic pathway for deriving actionable strategies for demand-side response and energy flow optimisation within H4Cs.

EXPECTED RESULTS

The ongoing research aims to get insights into the impact of industrial flexibility potentials on the energy-based optimisation of symbiosis networks. By representing energy-intensive industries with process-resolved synthetic load profiles, the approach should enable the identification of promising flexibility options and their quantitative potentials. Moreover, the research is anticipated to demonstrate how embedding industrial DSF into H4Cs enhances renewable integration, reduces system costs, and supports the development of resilient and resource-efficient regional energy systems as well as provide actionable knowledge for both industrial stakeholders and policymakers.

REFERENCES

[1] ANDERL, Michael; BARTEL, Andreas; BÜRGER, Johanna; GÖSSL, Michael; HAYDN, Martina; HEINFELLNER, Holger: Climate Protection Report 2023. Vienna, 2023 (Report / Umweltbundesamt REP-0871)

[2] FEDERAL MINISTRY REPUBLIC OF AUSTRIA CLIMATE ACTION, ENVIRONMENT, ENERGY, MOBILITY, INNOVATION AND TECHNOLOGY: Energy in Austria : Statistics, data, facts. Vienna, 2022

[3] NATIONAL COUNCIL OF AUSTRIA: Natural Gas Act (idF v. last amended on 22. 3. 2023) (BGBl. I Nr. 107/2011). URL

https://www.ris.bka.gv.at/GeltendeFassung/Bundesnormen/20007523/GWG%202011%2c%20Fassung%20vom%2015.06.2024.pdf – Überprüfungsdatum 2024-06-15

[4] NATIONAL COUNCIL OF AUSTRIA: Federal Act on the Expansion of Energy from Renewable Sources (idF v. last amended on 30. 12. 2022) (BGBl. I Nr. 150/2021). URL https://pvaustria.at/wp-content/uploads/Austrian_Renewable_Energy_Expansion_Act_1645214803.pdf – Überprüfungsdatum 2024-06-15

[5] Österreichs E-Wirtschaft. Stromerzeugung: Flexibilität zählt.

[6] Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie. Integrierter österreichischer Netzinfrastrukturplan.

[7] BINDERBAUER, Paul Josef; KIENBERGER, Thomas; STAUBMANN, Thomas: Synthetic load profile generation for production chains in energy intensive industrial subsectors via a bottom-up approach. In: Journal of Cleaner Production 331 (2022), S. 130024

[8] Mohammad Mohammadi, Younes Noorollahi, Behnam Mohammadi-ivatloo, and Hossein Yousefi. Energy hub: From a model to a concept – a review. Renewable and Sustainable Energy Reviews, 80:1512–1527, 2017. doi: https://doi.org/10.1016/j.rser.2017.07.030.

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CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: “Industrial and Urban Symbiosis”, „Circular Economy Strategies for the Energy Transition“, „Flexibility and Stability in Thermal and Electric Grids“

SODIUM TRISILICATE AS STABILIZER OF LI_2SO_4–NA_2SO_4 SOLID–SOLID PCMS FOR HIGH-TEMPERATURE THERMAL ENERGY STORAGE

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SUMMARY

The Li_2SO_4–Na_2SO_4 (LNS) system is a promising candidate for thermal energy storage in the 450–550 °C range due to the solid–solid transition of $LiNaSO_4$. However, its practical application is constrained by structural deformation upon cycling. In the present study, the effect of various additives, including MgO, graphite, and bentonite, was evaluated; these showed only limited effectiveness in improving the stability of the system. In contrast, the incorporation of sodium trisilicate ($Na_2Si_3O_7$) proved to be significantly more effective. The gelation ability of the silicate promoted the formation of a silica matrix that confined the LNS and contributed to enhancing its structural stability. Nevertheless, this process also induced Na^+ migration into the LNS, making it necessary to adjust the initial composition of the system in order to achieve a final 50:50 ratio. Comprehensive structural and microstructural analyses (SEM, XRD, FTIR) clarified the stabilization mechanisms associated with silicate incorporation. Moreover, thermal and cycling tests confirmed the preservation of approximately 90% of the enthalpy and a substantial improvement in shape stability, with no evidence of deformation after 100 cycles within the 300–580 °C range.

INTRODUCTION

The growing energy demand and the integration of intermittent renewable sources call for efficient thermal energy storage systems, particularly at high temperatures, as required in industrial processes and concentrating solar power plants. In this context, latent heat storage using solid–solid phase change materials (PCMs) is of great interest, since it offers high energy densities and reversible transitions without the corrosion or segregation issues typically associated with solid–liquid materials.

Within this framework, the Li_2SO_4–Na_2SO_4 (LNS) system emerges as a particularly attractive candidate, as it exhibits two notable compositions associated with solid–solid transitions: 21/79 and 50/50 molar. In particular, the 50:50 composition undergoes a solid–solid transition with an energy density of ≈158 J/g, good reversibility, and potential compatibility with air (Doppiu et al., 2019). However, its practical implementation has been limited by the instability observed after successive thermal cycles, manifested primarily as structural deformation and loss of mechanical integrity, although without significant reduction in transition enthalpy (Taeño et al., 2024).

To address these limitations, different inorganic additives (MgO, expanded graphite, bentonite, among others) have been evaluated, but none stabilized the cycling behavior of LNS. Motivated by the structural role of silicates in ceramics (Bayoumi et al., 2022), sodium trisilicate ($Na_2Si_3O_7$) is herein proposed as stabilizer.

METHODOOGY AND CHARACTERIZATION

The Li_2SO_4–Na_2SO_4 (LNS) composition was prepared from commercial salts (≥99%, Alfa Aesar) by ball milling and subsequent thermal treatment at 550 °C. Sodium trisilicate (5, 9 and 15 wt%) was incorporated with adjusted

stoichiometry to compensate for Na^+ migration and to ensure a final 50:50 composition. The mixtures were pressed and pretreated at 120 °C to remove residual water and promote silica gel formation.

Structural and microstructural characterization was carried out by XRD (phase identification), SEM and FTIR (morphology and silica gel confirmation), while DSC was used to evaluate transition enthalpies. Cycling tests between 300 and 580 °C were performed to assess shape stability and durability.

RESULTS AND CONCLUSIONS

The X-ray diffraction patterns of the Li_2SO_4–Na_2SO_4 (50:50) composition stabilized with sodium trisilicate show that the main phase corresponds to $LiNaSO_4$. After thermal treatment and cycling, a secondary phase attributable to lithium silicate appears, resulting from partial interaction between LNS and the trisilicate. The silica gel does not appear as a distinct phase in the XRD patterns, since it is amorphous. Nevertheless, $LiNaSO_4$ remains the predominant constituent, confirming preservation of the material's functionality.

Complementary SEM micrographs reveal the formation of a porous silica gel derived from sodium trisilicate. This continuous matrix acts as a rigid scaffold that buffers expansion and confines the LNS during cycling, thereby limiting macroscopic deformation. After cycling, penetration of LNS into the pores of the matrix is observed, suggesting a physical anchoring effect that enhances structural stability and reduces segregation. FTIR analysis supports these observations by displaying characteristic signals of silicate groups, in particular Si–O vibrations and terminal Si–OH groups, confirming persistence of the silica matrix after cycling.

In agreement with these structural and microstructural findings, calorimetric measurements (DSC) demonstrate that the characteristic solid–solid transition of the 50:50 LNS composition is preserved after trisilicate incorporation, with a transition enthalpy close to 90% of the theoretical value. This value remains essentially unchanged after repeated cycling, highlighting the effectiveness of the stabilizing agent.

Finally, operational stability was validated through 100 consecutive cycles between 300 and 580 °C, applying heating/cooling ramps of 5 $K \cdot min^{-1}$ with 15 min isotherms at each endpoint. Under these conditions, no significant losses in storage capacity or shifts in transition temperatures were observed, confirming the high thermal stability and reversibility of LNS stabilized with sodium trisilicate. Importantly, this study represents the first demonstration of an effective strategy to resolve the stability issue in the LNS system and, more broadly, in solid–solid PCMs designed for high-temperature applications.

ACKNOWLEDGMENT

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REFERENCES

Doppiu, S. et al., (2019), The Li_2SO_4–Na_2SO_4 System for Thermal Energy Storage. Materials, 12, 3658. MDPI, Basel, Switzerland.

Taeño, M. et al., (2024), Improved Thermophysical and Mechanical Properties in $LiNaSO_4$ Composites for Thermal Energy Storage. Nanomaterials, 14, 78. MDPI, Basel, Switzerland.

Bayoumi et al., (2022), Silicate Binders. Cerámica y Vidrio, 61, 453–469. Sociedad Española de Cerámica y Vidrio, Madrid, Spain.

CONFERENCE TOPIC

Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage.

RECENT PROGRESS IN THERMOCHEMICAL ENERGY STORAGE MATERIALS (TCMS)

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SUMMARY

Heat applications in household and industrial applications consume approximately a third of a country´s total annual energy demand. For the reduction of fossil fuels as primary energy source industrial waste heat storage and reuse and/or use of solar-thermal heat can contribute significantly via a temporal (and maybe spatial) decoupling of supply and demand. Therefore, the design and optimization of thermochemical energy storage materials to meet the application requirements is of utmost importance. Reversible solid-gas reactions are used to store and release heat. For large-scale use of this technology the reaction mechanisms need to be understood on molecular and particle scale and cycle stability and overall system performance on reactor scale. This presentation focuses on the challenges and chances of selected TCMs.

INTRODUCTION

After a systematic search for new materials based on a novel data base search algorithm (see Figure 1) [1] we focused our interest on solid gas reactions with water vapour and more recently with ammonia. There are two

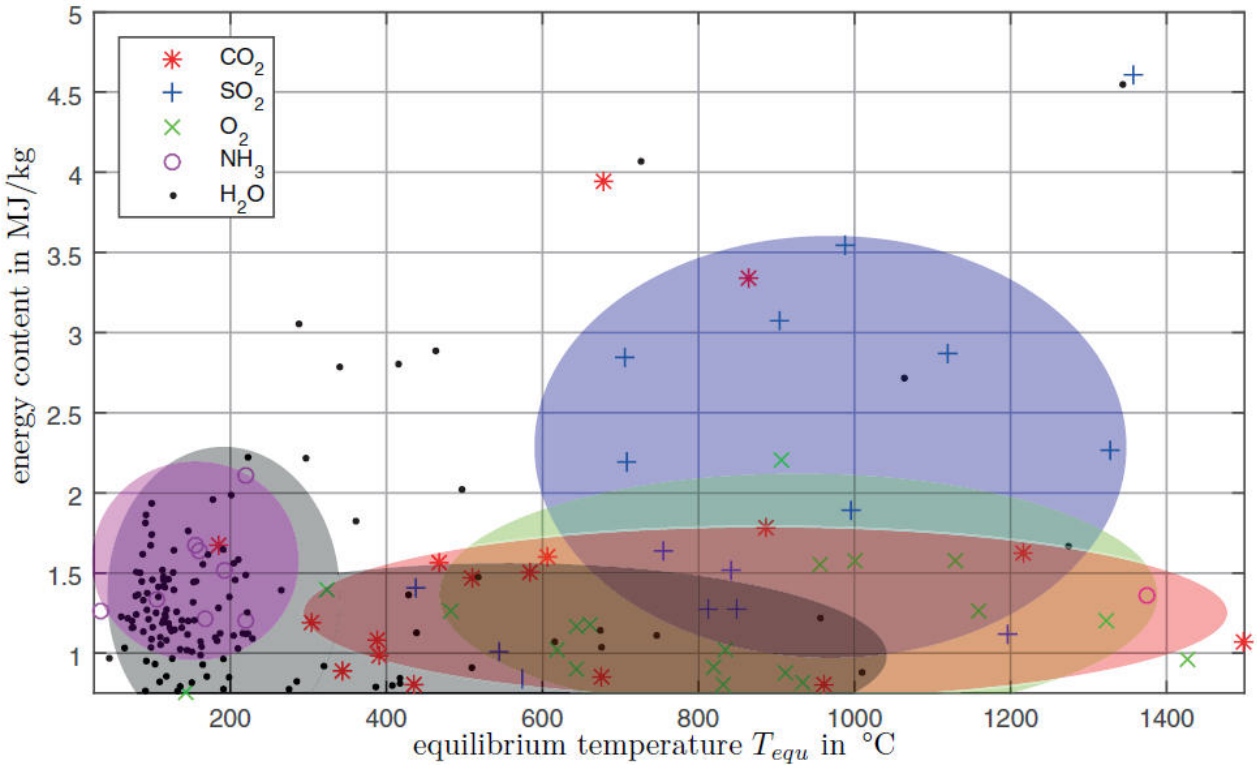


Fig. 1: Systematic investigation of potentially suitable solid materials for thermochemical energy storage with different gas compounds [1]

fundamentally different reaction schemes using water. On the one hand the reaction of oxides to hydroxides [2 – 4] and on the other hand the reaction of anhydrous salts to salt hydrates [5 – 8]. Especially, with respect to a tuneability of the hydration – dehydration temperature ranges the novel class of Tutton salt hydrates is of special interest [7]. For highest energy storage capacity, however, the class of transition metal salt ammoniates features volumetric storage densities in the range of GJ/m^3 [9].

THE TUTTON SALT HYDRATES

The class of the so-called Tutton salts [7] represents solid solutions of the general chemical composition $A_2M_{1-x}M'_x(SO_4)_2 \cdot 6\,H_2O$ with A being a monovalent cation such as NH_4^+, Na^+, K^+, etc… and M and M´ being divalent cations such as Mg^{2+}, Zn^{2+}, Ni^{2+}, Cu^{2+}, Co^{2+},…A few examples are given to show the power of the tunability via composition variation (see Figure 2).

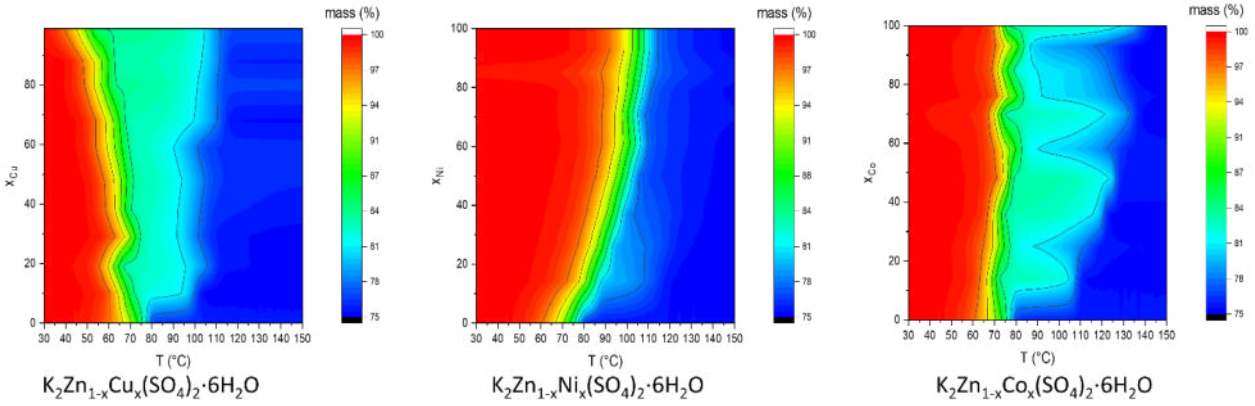


Fig. 2: A comparison of three selected series of solid solutions of the Tutton salts and their dehydration behaviour [7]

REFERENCES

[1] Deutsch, M. *et al.*; Applied Energy, 183 (2016) 113 – 120.
[2] Gravogl, G. *et al.*; Nanomaterials, 8 (2018) 795 (1-14).
[3] Müller, D. *et al.*; Adv. Sustainable Systems, 2 (2018) 1700096 (1-6).
[4] Müller, D. *et al.*; Applied Energy, 253 (2019) 113562, 1-11.
[5] Knoll, C. *et al.*; Applied Energy, 187 (2017) 1 – 9.
[6] Werner, J. *et al.*; Crystals, 13 (2023) 1518.
[7] Smith, J. *et al.*; J. of Energy Storage, 78 (2024) 110003.
[8] Smith, J. *et al.*; Measurements: Energy, 4 (2024) 100027 (1-10).
[9] Müller, D. *et al.*; Applied Energy, 285 (2021) 116470, 1-11.

CONFERENCE TOPIC

Conference Topics this abstract refers to: 1.13 Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

SPIRIT - SUSTAINABLE POWER INTEGRATION AND RECOVERY OF INDUSTRIAL THERMAL WASTE

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SUMMARY

Industrial processes across Europe release vast amounts of low-grade waste heat—thermal energy below 200°C—that remains largely untapped due to technological and economic limitations. The SPIRIT project addresses this challenge by developing a scalable plug-and-play solution for industrial environments, based on TEGnology's patented Flex-TEG® modules applicable to a wide range of industrial sectors such as biomass, WtE, cement, and chemical processing, where heat losses are substantial. The Flex-TEG® system converts heat directly into electricity using solid-state, passive technology. The system is modular, retrofittable, and adaptable to curved or irregular surfaces. It replaces scarce tellurium with low-cost, sustainable materials like antimony and zinc. Within the project, partners work jointly to design and adapt the system into a complete product that can be seamlessly integrated into a biomass plant as a first application. Field installation and validation will be performed at ACCIONA's biomass plant in Spain, where it is expected to recover up to 4,700 MWh/year and enable CO_2 emissions reduction of ~600 tonnes annually. The project bridges lab-scale innovation with real-world deployment. SPIRIT's open science practices ensure data accessibility and replication potential and contributes to EU climate goals by enabling scalable, cost-effective industrial decarbonization.

INTRODUCTION

Industrial processes across Europe release vast amounts of low-grade waste heat—thermal energy below 200°C—that remains largely untapped due to technological and economic limitations. The SPIRIT project (Sustainable Power Integration and Recovery of Industrial Thermal Waste) addresses this challenge by developing and validating scalable plug-and-play solution based on TEGnology's patented Flex-TEG® modules, designed to convert low-grade thermal energy directly into electricity. This system-level innovation targets energy-intensive sectors such as biomass, waste-to-energy (WtE), cement, steel, and chemical processing.

Flex-TEG® operates via the Seebeck effect, using doped semiconductor materials to generate electric potential from temperature gradients. Unlike conventional recovery technologies such as Organic Rankine Cycle (ORC) or Kalina systems, which require complex fluid dynamics and high operating temperatures, Flex-TEG® is a solid-state, passive system that functions efficiently below 200°C. Its modular and flexible design allows installation on curved and irregular surfaces, enabling retrofitting onto existing infrastructure without major modifications. This adaptability is critical for industrial environments where space, geometry, and operational constraints often hinder the deployment of rigid systems.

The SPIRIT project introduces several key innovations:

- Material substitution: Replacing scarce and expensive tellurium (~$100–150/kg) with abundant, low-cost alternatives such as antimony, zinc, and magnesium (~$0.5–12/kg), significantly reducing production costs and enhancing supply chain resilience.

- Thermal interface engineering: Using ceramic sheets with tunable Al_2O_3 micro- and nanofibers to improve heat transfer and reduce thermal resistance by up to 50%, boosting overall TEG performance.
- Adaptive heat pathway control: Enabling dynamic adjustment to fluctuating thermal conditions, maximizing energy recovery across diverse industrial scenarios.
- Plug-and-play final product design: Co-developed with ACCIONA to ensure modularity, ease of installation, and adaptability to curved and irregular industrial surfaces, enabling seamless retrofitting in biomass, WtE, and other plants.

The project follows a four-phase methodology: (1) specification and design based on real industrial conditions, (2) laboratory testing and optimization, (3) field integration and validation at ACCIONA's biomass plant in Spain, and (4) techno-economic and deployment strategy assessment. Initial projections suggest that Flex-TEG® can recover up to 4,700 MWh of electricity annually from a typical 15 MW biomass plant, reducing CO_2 emissions by approximately 600 tonnes per year. These results are supported by real-world data and simulations, with performance benchmarks aligning with state-of-the-art TEG systems.

The consortium behind SPIRIT is transnational including: TEGnology (Denmark), TU Wien (Austria), ACCIONA (Spain), and DTU (Denmark) with a strong link between innovation, industrial relevance, and policy alignment. The project contributes to the EU's climate neutrality goals by enabling scalable, cost-effective energy recovery and reducing reliance on fossil fuels. It also embraces open science principles, making non-confidential datasets and performance results publicly available to accelerate replication and further research. SPIRIT offers a practical, scalable, and sustainable solution for converting previously wasted heat into valuable electricity supporting Europe's clean energy transition and industrial decarbonization.

KEY WORDS

Thermoelectric Generator (TEG), Low-Grade Waste Heat Recovery, Flexible Energy Harvesting, Industrial Decarbonization, Scalable Clean Technology

REFERENCES

Lan, Y., Wang, S., et al. (2022). Comparative analysis of organic Rankine cycle, Kalina cycle and thermoelectric generator to recover waste heat based on energy, exergy, economic and environmental analysis method. Energy Conversion and Management, 273, 116401. https://doi.org/10.1016/j.enconman.2022.116401
Jouhara, H., et al. (2021). Thermoelectric generator (TEG) technologies and applications. International Journal of Thermofluids, 9, 100063. https://doi.org/10.1016/j.ijtf.2021.100063
Ying, P., et al. (2021). Towards tellurium-free thermoelectric modules for power generation from low-grade heat. Nature Communications, 12, 1121. https://doi.org/10.1038/s41467-021-21391-1
Li, Y., et al. (2023). Thermal and electrical contact resistances of thermoelectric generator: Experimental study and artificial neural network modelling. Applied Thermal Engineering, 225, 120154. https://doi.org/10.1016/j.applthermaleng.2023.120154
Bloomberg (2023). Harnessing Waste Heat Could Save Europe €65 Billion. https://www.bloomberg.com/news/articles/2023-02-22/harnessing-waste-heat-could-save-67-billion-for-europe

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: 1.06. Excess Heat and Resource Recovery from Low-grade Sources

FROM STATIC ENERGY AUDITS TO DYNAMIC LIVING LABS: A MULTI-STAGE AUDIT SYSTEM FOR CARBON-NEUTRAL THERMAL SPAS IN AUSTRIA

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SUMMARY

Thermal spas in Austria are highly energy-intensive and still largely dependent on fossil fuels. The GEO.MAT project introduces a **multi-stage Audit System** that extends conventional audits into a continuous process combining monitoring, simulation, system optimization, and predictive control. Two **Living Labs** – Sonnentherme Lutzmannsburg and H2O Hoteltherme Bad Waltersdorf – demonstrate how cascaded heat pumps, stratified storages, and waste heat recovery can cut emissions by over 1,200–1,400 t CO_2 annually per site. With modelling nearly completed, the next step is real-world implementation of selected measures, accompanied by iterative evaluation, continuous monitoring, and predictive control testing. Thermal spas thus emerge as **real-world laboratories for decarbonization** with high replication potential.

Keywords: energy audit system, thermal spas, living lab, waste heat recovery, flexibility, predictive control

INTRODUCTION

Thermal spas represent one of the most energy-intensive sectors in Austria's tourism industry, with annual heat demands between 5 and 16 GWh per site and electricity consumption of up to 6 GWh. Historically, these facilities have relied heavily on fossil fuels, particularly natural gas, creating both ecological and economic challenges. A baseline survey of representative sites confirms this dependency and quantifies the load distribution per energy carrier (e.g. 16 GWh/a of natural gas at Sonnentherme Lutzmannsburg; 6.4 GWh/a of biomass and 3.4 GWh/a of electricity at H2O Hoteltherme Bad Waltersdorf) [1,2]. These findings highlight the urgency of a systematic transformation approach and provide robust reference points for subsequent modelling and validation.

A MULIT-STAGE AUDIT SYSTEM

Therefore, a **multi-stage Audit System** has been developed in the research project GEO.MAT that extends conventional energy audits into a *continuous, adaptive cycle*. It links (i) **status-quo assessment and benchmarking** combined with targeted measurement campaigns, (ii) **dynamic building and comfort simulation** (IDA ICE) to capture thermal envelopes, evaporation, and visitor-driven loads, (iii) **digital twin modelling and energy system optimization** (Python, MILP) for hybrid heating/cooling/electricity systems including geothermal wells, compression heat pumps, photovoltaics, biomass, and stratified storages, (iv) **efficiency-first measures** (temperature-level optimization, hydraulic balancing, ventilation heat recovery), (v) **investment and funding roadmaps**, and (vi) **long-term monitoring with predictive control** (MPC/DPC). This perspective enables simultaneous optimization of operating modes, source/sink temperatures, and storage stratification, while deriving threshold values for component sizing such as heat pump capacity.

PERFORMANCE OF LIVING LABS

Living Lab 1 – Sonnentherme Lutzmannsburg. Hourly gas load profiles and on-site measurements of key consumers (sport and buffer pools) show pronounced morning peak loads, which can be significantly reduced through predictive control strategies. Measurement campaigns identified untapped energy sources: splash water at ~30 °C (~1,230 m³/week) and condenser waste heat from a chiller (~790 kW) [3]. Coupled with compression heat pumps and stratified storage, these sources provide substantial substitution of fossil fuel demand. Implementation results confirm carbon savings exceeding 1,200 t CO_2 annually, while predictive control ensures load smoothing during high visitor demand periods.

Living Lab 2 – H2O Hoteltherme Bad Waltersdorf. This facility integrates a geothermal well (9 m³/h, 32 °C) with a biomass heating plant. The audit quantified three scalable waste heat sources exploitable in a cascaded manner: splash water (~670 MWh/a), ventilation exhaust/cooling water (~1 GWh/a), and drinking water cooling (~2.7 GWh/a, available year-round) [3]. The system design employs cascaded compression heat pumps (sources at 14/20/30 °C; condensation at 55/70 °C) and stratified cold and hot water storages. This configuration minimizes mixing losses, enables bidirectional integration with district heating, and increases exergetic efficiency. First results demonstrate annual CO_2 reductions of >1,400 t while maintaining thermal comfort and operational reliability [4].

The modelling of the Living Labs is nearly completed, providing optimized system designs and validated operation strategies. The next phase focuses on real-world implementation of selected measures, including waste heat recovery, cascaded heat pumps, and storage integration. These implementations will be iteratively evaluated, scientifically accompanied, and continuously monitored. On this basis, the predictive control system will be set up and tested under real conditions, ensuring that the planned efficiency and flexibility gains are achieved in practice. The combination of simulation, implementation, and validation provides transferable knowledge that extends beyond spas to other energy-intensive infrastructures.

CONCLUSION

The GEO.MAT Audit System establishes thermal spas as Living Labs for decarbonization. By combining rigorous monitoring, dynamic simulation, cascaded heat pump integration, stratified storages, and predictive control, the Living Labs demonstrate substantial carbon savings, peak-load reduction, and operational resilience. With the transition from modelling to implementation now underway, the iterative validation of measures and deployment of predictive control will further strengthen robustness and scientific insight. The project advances the concept of continuous audits, hybrid energy system optimization, and replicable pathways for systemic decarbonization in tourism and beyond.

REFERENCES

(1) Novakovits, P. (2018): Entwicklung einer Methodik zur Erstellung eines Energieeffizienz-Benchmarks für Hotels sowie für Kur- und Gesundheitseinrichtungen anhand der Kurbad Tatzmannsdorf AG, Masterarbeit, Fachhochschule Burgenland, Pinkafeld.

(2) Seidnitzer-Gallien, C., Bühne, X., Gumhalter, M. (2024a): CO2-freie Therme – Erhebung, Benchmarks und Konzepte zur Dekarbonisierung und Energietransformation. In: Proceeding e.nova International Conference, 2024, DOI: https://doi.org/10.57739/978-3-903207-89-9

(3) Seidnitzer-Gallien, C., Stelzer R., Dragosits, S. (2024b): Use of waste heat potential and flexibility elements to speed up decarbonisation in Austrian thermal spas. In: Proceeding 3rd International Sustainable Energy Conference, 2024, DOI: https://doi.org/10.52825/isec.v1i.1262

(4) Kaisermayr, V., Fuchsberger, J., Muschick, D, et.al. (2025): A Smart System Integrating Waste Heat Recovery, Heat Pumps and PV to Unlock the Energy Potential of Thermal Baths. 11th International Conference on Smart Energy Systems, Copenhagen.

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CONFERENCE TOPIC

Main related Conference Topics of the abstract

- **Excess Heat and Resource Recovery from Low-grade Sources**
- Building the Future: Smart Energy Infrastructure for the Energy Transition

ELECTRICITY, HEAT AND GRID SERVICES - INVESTIGATION OF ECONOMIC EFFICIENCY OF THERMAL STORAGE POWER PLANTS

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SUMMARY

This paper analyses the simultaneous consideration of various revenue streams in order to evaluate the economic efficiency of Thermal Storage Power Plants (TSPP) across different applications. TSPP integrate a high-temperature heat storage system with a power-to-heat unit into thermal steam or combined cycle power plants. Using Mixed-Integer Linear Programming energy system optimization, the technology is evaluated in terms of its economic performance with simultaneous participation in different energy markets. The influence of the different revenue streams on general economic efficiency and robustness against changing market conditions is analyzed.

INTRODUCTION

The concept of Thermal Storage Power Plants was developed by the DLR as a solution to the residual load problem of renewable energy systems [Trieb et. al. 2022]. Figure 1 shows the technical concept.

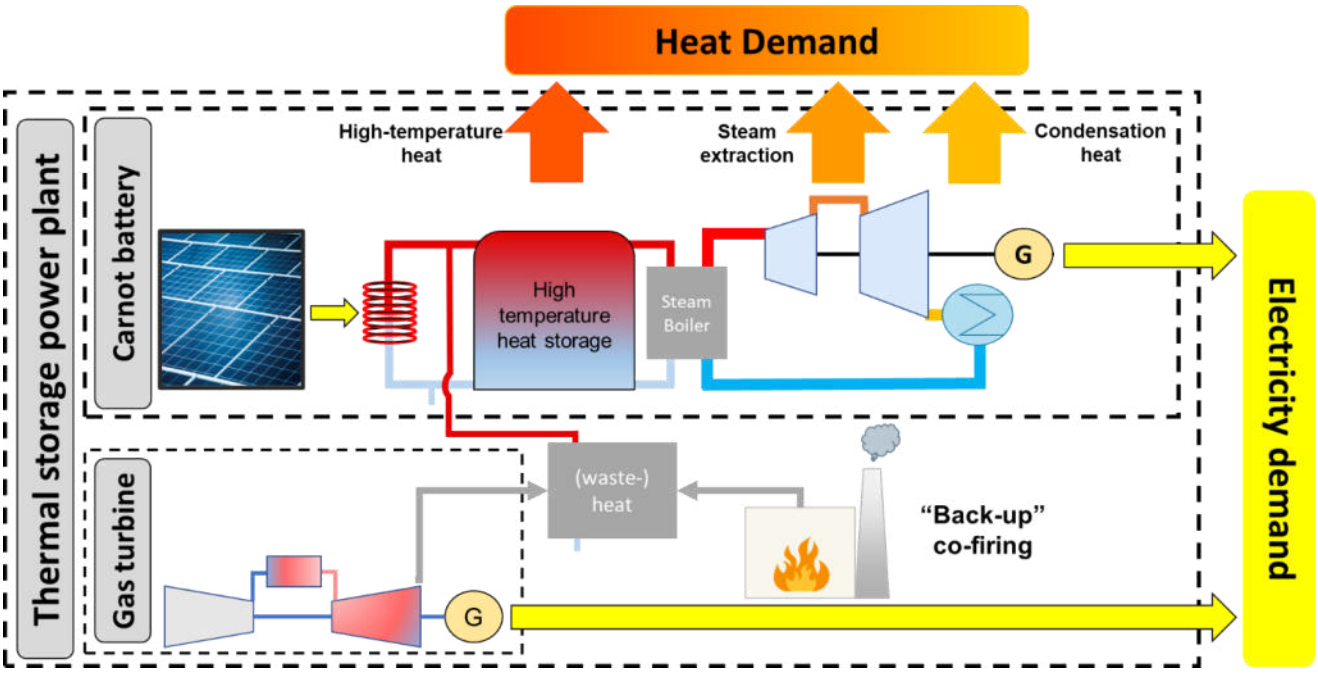


FIG. 7: THERMAL STORAGE POWER PLANT CONCEPT

A TSPP is comprised of a photovoltaic power plant, a gas turbine, a Carnot battery with an associated steam turbine and a backup (biofuel) heater. When the TSPP's photovoltaic park generates electricity during times of favourable electricity prices, it will be fed directly into the grid. Otherwise, the electricity is converted into heat using an electric heater and stored in the high-temperature heat storage system. Surplus electricity from the grid

can be used for the same purpose, which alleviates grid congestion and simultaneously provides the TSPP with favourably priced energy. In times when demand exceeds the generation of the PV system heat from the storage tank is used to generate steam, which is then expanded via a turbine and generator to supply electricity.
In order to guarantee the permanent coverage of the residual load, an additional auxiliary firing system produces steam when needed. In comparison to a conventional thermal power plant, the fuel requirement of a TSPP is significantly reduced by PV electricity added directly or through the Carnot battery. Furthermore, a gas turbine is integrated into the TSPP system to provide additional capacity during periods of high electricity prices. The reject heat from the gas turbine is recovered by feeding it into the storage and / or the steam cycle, allowing the steam for the steam turbine to be generated either simultaneously or with a time delay. Due to the integrated storage and the independent operation of the gas turbines, this configuration achieves the efficiency of a combined cycle process, while the gas turbine retains the flexibility of an open cycle gas turbine. This way, a TSPP is also able to participate on the frequency control market with the gas turbine or the flexible operation of the electric heater.
When commercially available, the gas turbine, as well as the co-firing unit, can be converted to renewable fuels to ensure secure, flexible and green energy. TSPP allow for sector coupling, both for electricity and heat supply. High temperature heat can be taken directly from the thermal storage, steam can be extracted from the turbine at the required temperature and pressure, and low temperature heat such as district heat can be supplied by low pressure steam or condensation heat.

METHODOLOGY

Thermal storage power plants are a versatile technology that can participate in various markets. To assess their full economic potential, it is necessary to consider the possible markets in parallel, especially as simultaneous participation in several markets is sometimes not possible or is associated with restrictions (e.g. reserving capacity for frequency control and participating on the wholesale electricity market). During this study, the wholesale electricity market, district heating, industrial heat, automatic frequency replacement reserve (aFRR) and potential future revenues for synchronous inertia and a capacity market are considered.
Economic efficiency is evaluated using Mixed-Integer Linear Programming optimisation. For this purpose, the Top-Energy® tool is used. To enable modelling that is as close to reality as possible, the technical system is first mapped using thermodynamic simulation to calculate the potential operating boundaries (e.g. full load, full load with heat extraction, minimum part load, etc.). These results are then abstracted into energy flows and efficiencies, and existing correlations are linearised. These can then be used to create the linear optimisation problem. This optimisation problem provides results for optimised component sizing and operating behaviour. Thus, a techno-economic analysis is performed, taking into account various revenue streams, particularly combined participation in the electricity, heat, and grid transmission markets. Sensitivity analyses are performed for various boundary conditions, such as fuel prices, investment costs and electricity prices.

RESULTS

The result of the optimization is an economic assessment of Thermal Storage Power Plants across different scenarios and applications. It calculates the potential annual costs and revenues, as well as the optimized operation and behavior of the related plant. The influence of each market participation on the overall economic performance is demonstrated, as well as which markets should be prioritized and whether and how simultaneous participation in several markets is possible. These results are generated for a variety of scenarios, which vary according to the markets in which the TSPP participates. Sensitivity analyses demonstrate the impact of varying boundary conditions on promising or interesting scenarios. They show how revenue shares from different market participations vary and how the TSPP configuration can be adjusted. Together, these results provide guidelines

on how to best adapt to changes in the energy market and demonstrate how diversifying revenue sources can improve the economic robustness of such power plants.

REFERENCES

Trieb, F., Liu, P., Koll, G., (2022), Thermal Storage Power Plants (TSPP) – Operation mode for flexible renewable power supply, Journal of energy storage, https://doi.org/10.1016/j.est.2022.104282

CONFERENCE TOPIC

This abstract mainly refers to the following Conference Topics:

- 1.04 Coupling of Energy Sectors
- 1.12 Next-Generation Technologies for Renewable Energy and Resource Efficiency
- 1.13 Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

SUPPLY-SIDE OPTIMISATION AND P2H SIZING FOR A 2040 NET-ZERO DISTRICT HEATING SYSTEM: THE KAPFENBERG CASE

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SUMMARY

This study, conducted within the SUPPORT DHC project, investigates supply-side optimisation pathways for Stadtwerke Kapfenberg's district heating system targeting full decarbonisation by 2040. Using energyPRO, cost-optimal supply portfolios and Power-to-Heat (P2H) sizing were evaluated under four scenario families, reflecting current and prospective boundary conditions. Results highlight the pivotal role of industrial waste heat utilisation, PV-coupled and grid-enabled P2H integration, and the marginal value of P2H capacity under varying operational constraints. The work provides a replicable optimisation framework for municipal operators, delivering decision-ready insights that support stepwise transition planning towards 100% renewable and waste heat supply.

BACKGROUND AND MOTIVATION

Decarbonizing Europe's District Heating and Cooling (DHC) requires the accelerated integration of low-grade Renewable Energy (RE) and Waste Heat (WH) sources, while ensuring affordability and system reliability. Earlier research has demonstrated that modernization and retrofitting of district heating networks are crucial to achieve substantial reductions in fossil fuel consumption and greenhouse gas emissions, with evidence of up to 40% CO_2 savings in practical scenarios [1].

In this context, Stadtwärme Kapfenberg GmbH has aligned its strategy with Austria's climate neutrality objectives, setting ambitious targets to reduce fossil fuel dependency and progressively transform its heat supply portfolio towards renewable and low-carbon sources. Integrated district-level planning studies confirm that coordinated supply- and demand-side measures, combined with the expansion of district heating networks, offer the most cost- and carbon-optimal decarbonization pathways [2].

The SUPPORT DHC project directly addresses this challenge by fostering the rapid uptake of RE and WH through targeted technical measures for upgrading distribution systems by noting the methodological advances in multi-criteria decision frameworks for local heating modernization [3]. Against this backdrop, the Kapfenberg case study provides a concrete testbed to demonstrate how innovative planning and optimization approaches can accelerate the transition to a fully renewable and waste-heat-based supply system.

CASE STUDY CONTEXT: STADTWERKE KAPFENBERG

The district heating system of Stadtwärme Kapfenberg GmbH represents a medium-sized municipal utility undergoing a decisive transformation towards climate neutrality. At the onset of the SUPPORT DHC collaboration, the system consisted of one main network and seven micro-grids, serving 1,357 customers with an annual demand of 23.7 GWh. To reach Kapfenberg's goal to become climate neutral, a systematic transition strategy was necessary.

A staged expansion plan for 2026 – 2028 foresees the integration of additional waste heat from Norske Skog in Bruck an der Mur, the upscaling of Böhler's surplus heat, and the construction of a 5 MW biomass boiler with 1,000 m³ thermal storage. Within this framework, SUPPORT DHC specifically evaluates Power-to-Heat (P2H) integration through energyPRO modelling, targeting cost-optimal sizing, operational flexibility, and alignment with Austria's climate neutrality objectives.

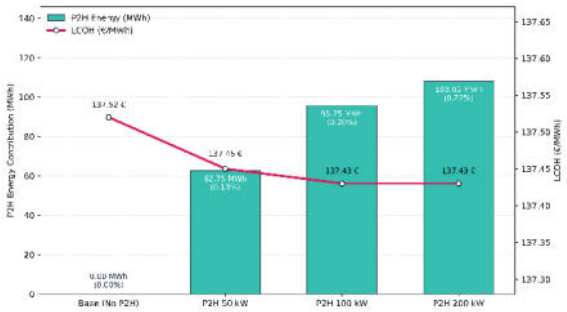
METHODOLOGICAL FRAMEWORK

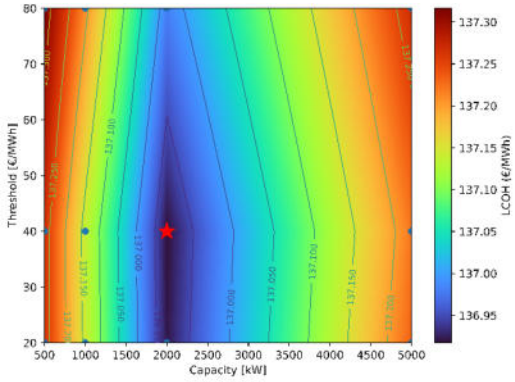
This contribution presents a techno-economic study for Stadtwärme Kapfenberg GmbH to guide near-term investment decisions in line with the operator's objective of fully decarbonising all district heating networks by 2040. Heat-supply options were evaluated under current and prospective boundary conditions, explicitly accounting for planned network expansions and the integration of RE and WH sources already by the operator. The analysis pursued having the main objective to size a P2H unit under two operational modalities (PV-only and PV + grid) using the energyPRO tool. Hourly dispatch was optimised over a full year, based on validated demand series and reflecting real-world constraints: source availability and maintenance windows, operator-defined merit-order priorities, operational cost parameters, indicative capacity bounds, and applicable tariffs.

RESULTS

The optimisation results reveal distinct operational and economic outcomes across the scenario families. In the reference case without P2H, the system is dominated by industrial waste heat contributions, while neither the new biomass plant nor the gas boilers are dispatched under cost-optimal conditions.

In the PV-only case, the contribution of P2H grows with installed capacity. Yet, the impact on the Levelized Cost of Heat (LCOH) is marginal, since P2H is restricted to operating on solar generation and the PV-only case was included as a methodological reference only. While such a configuration provides a benefit for a district heating system, it demonstrates the constrained operational space of P2H without access to grid electricity.





The PV + grid case highlights the pivotal role of electricity market interaction. Figure 2 presents a contour map of LCOH as a function of P2H capacity and purchase-price threshold, below which electricity is used for the P2H system Here, both the extent of P2H utilisation and cost-effectiveness depend strongly on the threshold. The lowest LCOH is achieved at approximately 2,000 kW installed capacity with a grid-price limit of 40 €/MWh (marked with a red star). Beyond this point, additional capacity yields diminishing returns, as low-price operating hours become saturated.

REFERENCES

[1] Zajacs, A; Borodinecs, A; Vatin, N. Environmental Impact of District Heating System Retrofitting. Atmosphere 2021, 12, 1110. https://doi.org/10.3390/atmos12091110

[2] Lerbinger, A; Petkov, I; Mavromatidis, G; Knoeri, C. Optimal decarbonization strategies for existing districts considering energy systems and retrofits. Applied Energy 2023, 352, 121863. https://doi.org/10.1016/j.apenergy.2023.121863

[3] Mróz TM. Planning of community heating systems modernization and development. Applied Thermal Engineering 2008, 28. https://doi.org/10.1016/j.applthermaleng.2007.11.020

CONFERENCE TOPIC

- Primary topic: Future District Heating and Cooling Technologies
- Secondary topic: Coupling of Energy Sectors

PARABOLIC TROUGH COLLECTORS FOR EXISTING DISTRICT HEATING NETWORKS

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SUMMARY

Since many existing district heating systems operate with supply temperatures above 100 °C, renewable heat technologies such as parabolic trough collectors can play a key role in the decarbonization of existing district heating systems due to their ability to supply these high temperatures efficiently (IEA SHC Task 68 RA1, 2024). Investigations show that a wide range of calculation and simulation tools are available for solar district heating (SDH) systems, especially those that use concentrating solar thermal technologies such as parabolic trough collectors (IEA SHC Task 68 RA2, 2025).
The goal of this presentation is to ensure that simulation tools, such as TRNSYS can accurately model the performance of parabolic trough collectors, thereby providing a reliable basis for integration into district heating. This work is part of the ongoing German research project ProSolNetz, funded by the German Federal Ministry for Economic Affairs and Energy (BMWE) (BSW, 2025) (TRNSYS, 2025).

INTRODUCTION

Studies conducted within the IEA SHC Task 68 and the German research project ProSolNetz demonstrate that parabolic trough collectors can deliver temperatures above 100 °C more efficiently than standard collectors like flat plate or evacuated tube collectors (IEA SHC Task 68 RA1, 2024).
Based on a survey completed by collector manufacturers, typical supply temperatures of various solar thermal technologies have been compared, see Figure 28. Concentrating technologies (orange bars) such as large parabolic troughs, Fresnel lenses, and linear Fresnel collectors achieve higher supply temperatures due to their ability to focus direct solar radiation. This means that parabolic trough collectors may be of particular interest for existing district heating networks with higher supply temperatures (IEA SHC Task 68 RA1, 2024).

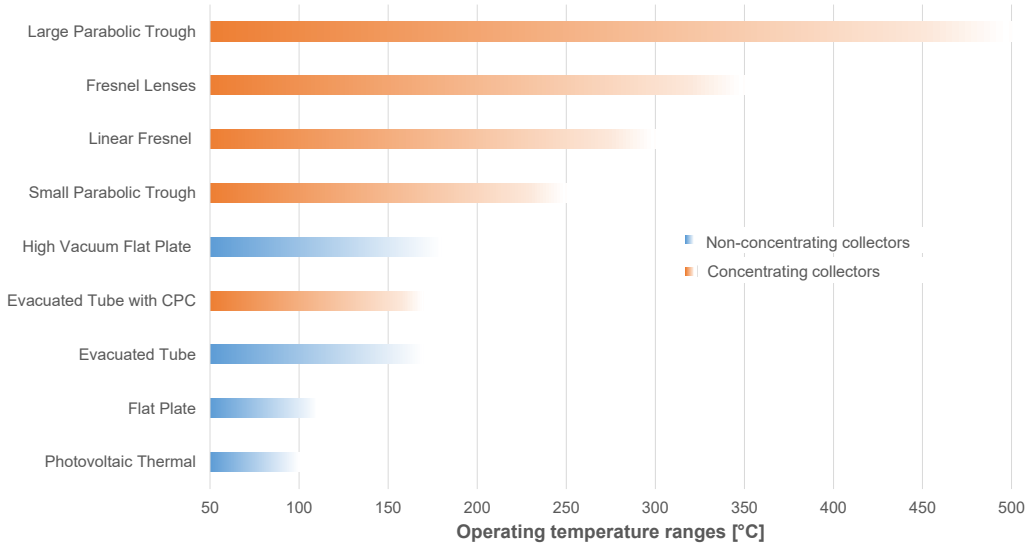


FIGURE 28 ...OUND PARABOLIC CONCENTRATOR). (IEA SHC TASK 68 RA1, 2024)

SIMULATION AND CALCULATION TOOLS FOR CONCENTRATING TECHNOLOGIES

In order to support the effective planning, design and optimization of SDH systems, it is crucial to identify which simulation and calculation tools are currently used in the sector. Based on a survey which has been conducted within IEA SHC Task 68, many planners and researchers rely on their in-house tools, although the majority stated that they use TRNSYS as their primary simulation software, see Figure 29 (IEA SHC Task 68 RA2, 2025).
On the one hand, the wide availability of suitable tools is promising. On the other hand, there is no guarantee for the accuracy and reliability of the results obtained with them. To ensure accurate simulations, it is essential to validate common tools using measurement data from real parabolic trough collector plants.

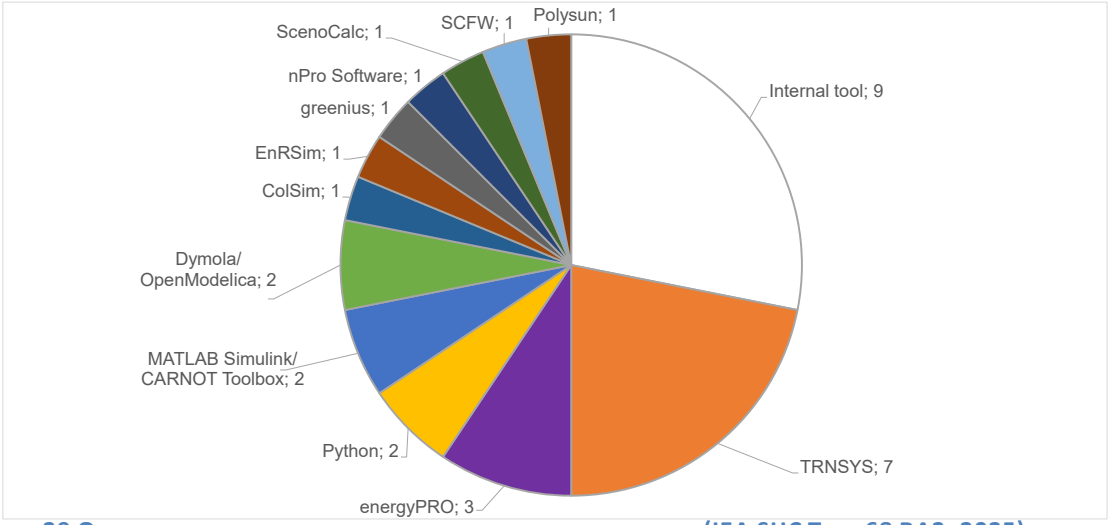


FIGURE 29 OVERVIEW OF TOOLS FOR WHICH THE SURVEY WAS COMPLETED (IEA SHC TASK 68 RA2, 2025)

FURTHER DEVELOPMENT OF SIMULATION AND CALCULATION TOOLS

SCFW (ScenoCalc Fernwärme – ScenoCalc District Heating) is an often-used German tool for calculating the solar thermal yield of systems integrated into district heating networks. SCFW considers the collector output according to DIN EN ISO 9806 and additional system components such as piping, heat exchangers, and thermal storage. This enables the calculation of the solar heat yield (SCFW, 2025). As part of the ProSolNetz project, the SCFW tool is currently being developed to version 3.0 and will be published in English as well. Planned improvements include among others an enhanced storage model and the consideration of tracking systems with shading effects. In addition to SCFW, the TRNSYS models of parabolic trough collectors are being further developed and validated using measurement data from two real parabolic trough collector plants. The validation considers important collector-specific effects, including sun tracking, row shading, defocusing, strategies to prevent stagnation, and the effects of collector soiling. As part of ProSolNetz, the software tool Greenius from DLR (German Aerospace Center) is being further developed as well. It is designed for simulating and forecasting the energy yield of concentrating solar power (CSP) plants over time, with a primary focus on industrial process heat applications (Greenius, 2025).

CONCLUSION

Studies, comparisons, and simulations conducted so far indicate that concentrating collectors such as parabolic troughs are promising for existing district heating systems. To support this potential, accurate simulation models for parabolic trough collectors need further development. Current results show that these collectors are particularly suitable for district heating systems that require supply temperatures above 100 °C. In the presentation, results of a validated system model in TRNSYS in comparison with measurement data and first results of the development of SCFW 3.0 are shown. In a subsequent step, other simulation tools may be aligned

with TRNSYS, enabling the development of reliable and comparable tools for the simulation and calculation of parabolic trough collectors in SDH systems in the future.

REFERENCES

IEA SHC Task 68 RA1 (2024), Solar Collector Technologies for District Heating, report RA1, doi.org/ 10.18777/ieashc-task68-2024-0002
IEA SHC Task 68 RA2 (2025), Simulation and Calculation Tools for Solar District Heating, report RA2, doi.org/10.18777/ieashc-task68-2025-0001
BSW Solar (Bundesverband Solarwirtschaft e.V.), Prozess- und Fernwärme mit konzentrierenden Solarkollektoren [online 14.7.2025], available from: www.solarwirtschaft.de/unsere-themen/csp/prosolnetz/
TRNSYS, 2025, TRNSYS-Transient System Simulation Tool, available from: www.trnsys.com/
SCFW (ScenoCalc Fernwärme) Ertragsvorhersagetool für Solarthermie-Anlagen in Wärmenetzen [online 08.09.2025], available from: www.scfw.de
Greenius, 2025 [online 08.09.2025], available from: www.dlr.de/en/sf/research-and-transfer/research-services/simulation-and-profitability-assessment/greenius/

CONFERENCE TOPIC

1.08. Future District Heating and Cooling Solutions

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

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A MINLP OPTIMISATION METHOD TO SOLVE HYDRAULIC BOTTLENECKS ON EXISTING DISTRICT HEATING NETWORKS

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SUMMARY

District heating networks are favoured in dense urban areas to decarbonise heating especially as they can use low-carbon energy sources. On many existing district heating networks, this entails operating with lower temperatures that cause some technical issues especially in the distribution part. Indeed, reducing the operation temperature leads to a hydraulic operation exceeding design specification. To choose the better retrofit solution, an optimization approach is required, including thermo-hydraulic variables, the topology and the dynamic behaviour of the network. This work proposes a method based on a mixed-integer non-linear formulation to mitigate hydraulic bottlenecks of a simple district heating network in a cost-effective way.

CONTEXT AND METHOD

The decarbonization of heating would go through the deployment of district heating networks (DHN) especially with low-carbon energy sources (IEA, 2025). That involves the retrofit of several assets on some existing DHNs as they need to reduce their operational temperature (Guelpa *et al.*, 2023). In the literature, many studies deal with buildings retrofit, others with substations resizing; however, few tackle the distribution part. Indeed, a reduction in temperature results in an overall increase in mass flow rates and thus velocities, exceeding the recommended limit in certain pipes. Usually, critical pipes are replaced with larger ones but in some cases, construction works are impossible or too expensive. Another solution is to introduce distributed storages which can locally reduce the mass flow rate in pipes shifting heat demand peaks to off-peak time (Lemelle *et al.*, 2025). For those storages, many different positions, sizes and strategies for operation are possible. To find the best trade-off between both solutions and their corresponding design, a wide exploration with optimisation tools is needed. Meta-heuristics are generally used but often time-consuming (Merlet, Baviere and Vasset, 2023) and quite limited to address operational aspects. This work proposes to tackle this issue using deterministic methods. Because of their capacity to represent more accurately the thermal-hydraulic behaviour of the network, non-linear formulations are typically more suited for operational optimization issues. On the opposite, in order to alleviate problem scaling issues, design and configuration problems are typically solved in the literature using linear formulation. In our context, a mixed-integer non-linear (MINLP) optimization initialized with a mixed-integer linear (MILP) and a non-linear (NLP) optimization is developed. The method combines a large number of variables required to describe the network topology, the complexity of modelling non-linear phenomena, and the need to account for dynamic behaviour.

CASE STUDY

The optimisation method is applied on a simple district heating network represented in Fig. 1. Heat requests for the four consumers – shop, residential, hospital and office – are satisfied by a production site composed of a waste, a biomass and a gas plant. Pipes and substations are originally designed for a supply temperature of 120°C. Four potential storages can be installed on the network, one centralized (stor 9) and three distributed (stor 1/2/5). The optimization solver has to minimize investment, maintenance and operation costs of the network under some constraints including mass and energy balances in pipes, heat exchanges at production site and substations,

maximal production plant powers, minimal substation temperatures and maximal pipe velocities. The optimisation is solved on GAMS with the

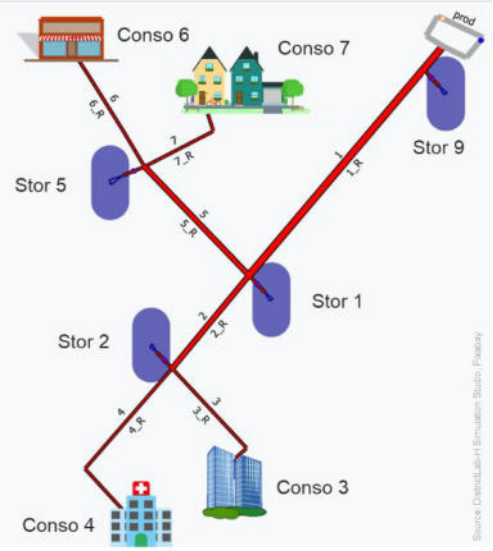


Fig. 1: Case study

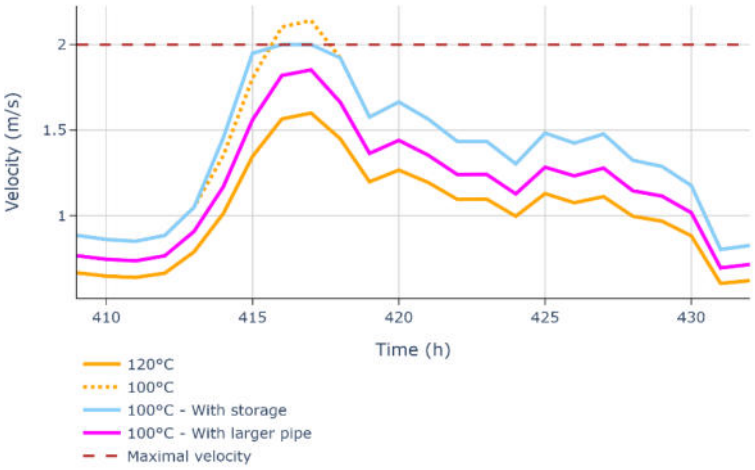


Fig. 2: Evolution of the velocity in the pipe 1

Artelys Knitro solver. The accuracy of the optimization results is evaluated with an equivalent simulation of the network on the software DistrictLab-H Simulation Studio (Baviere *et al.*, 2023).

Fig. 2 represents the velocity in the main pipe of the network – pipe 1 – according to the supply temperature and the retrofit option considered in each optimisation scenario. The first orange line gives the velocity when operating the network at its design supply temperature, i.e 120°C. The velocity still remains under the recommended maximal limit of 2 m/s, represented by the red dash line. When the supply temperature is reduced to 100°C, the velocity limit is exceeded as shown by the orange dotted line. First, the only retrofit solution allowed is to replace pipes with a larger diameter. This solution solves the hydraulic congestion as represented by the pink line. Secondly, the solver can install distributed storages without replacing pipes. To minimize losses, it chooses the storage 5 and operates it in order to shave the fluid velocity under the limit of 2 m/s as shown by the blue line. Those first results show how the optimisation problem solves hydraulic bottlenecks on the higher-demand day of the year installing a distributed storage or a larger pipe minimizing total costs. Supplementary results will assess over one year, which is the cheapest solution taking into account construction works to replace pipe and potential production peak-shaving of distributed storages on no-congestion days. This optimisation over the year will include the reduction of the demand profiles to representative days to enable the non-linear problem to be solved.

REFERENCES

Baviere, R. *et al.* (2023) 'DISTRICTLAB-H: A new tool to optimize the design and operation of district heating and cooling networks', in. *DHC Symposium 2023 - The 18th International Symposium on District Heating and Cooling*. Available at: https://cea.hal.science/cea-04247969.

Guelpa, E. *et al.* (2023) 'Reduction of supply temperature in existing district heating: A review of strategies and implementations', *Energy*, 262(125363). Available at: https://doi.org/10.1016/j.energy.2022.125363.

IEA (2025) *District Heating*. Available at: https://www.iea.org/energy-system/buildings/district-heating.

Lemelle, A.-G. *et al.* (2025) 'Les stockages distribués pour diminuer la température d'opération des réseaux de chaleur existants'. Available at: https://doi.org/10.25855/SFT2025-045.

Merlet, Y., Baviere, R. and Vasset, N. (2023) 'Optimal retrofit of district heating network to lower temperature levels', *Energy*, 282(128386). Available at: https://doi.org/10.1016/j.energy.2023.128386.

CONFERENCE TOPIC

1.15. Sustainable Renovation and Energy Retrofits (Potentially 1.07. Flexibility and Stability in Thermal and Electric Grids and 1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature…)

ZINC ZWISCHENSCHRITT ELECTROLYZER (ZZE) – A NEW APPROACH FOR EFFICIECIENT ENERGY STORAGE GREEN HYDROGEN PRODUCTION

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SUMMARY

Zinc Zwischenschritt Electrolyzer (zinc intermediate step electrolyzer, ZZE) is a highly effective and cost-efficient system that serves both, as an energy storage device for grid stabilization, and to produce green hydrogen. As the share of fluctuating energy is increasing due to an increasing ratio of renewable energy sources, this system can contribute to ensure a balanced supply of green electricity and green hydrogen for industry, households, and mobility. In our study, electrochemical parameters of a ZZE were investigated in a 50 cm^2 test cell to achieve highly reproducible results concerning optimal operating conditions and system capacity. System efficiency and hydrogen production cost were calculated in a defined application scenario.
Keywords: Zinc Zwischenschritt Electrolyzer (ZZE), green hydrogen, electrolysis, energy storage

INTRODUCTION

Austria's hydrogen strategy is the foundation for building an innovative and focused hydrogen economy that will help the country achieve climate neutrality. In addition, there is an obligation to comply with European energy and climate targets. As an energy carrier, climate-neutral hydrogen provides security of supply in industry, mobility, and households. Currently, it is mainly produced through PEM and alkaline electrolysis systems using green electricity. However, green electricity is subject to severe competition and is highly fluctuating, especially when generated from wind and solar energy, which has a negative impact on the cost of hydrogen production. The ZZE is a highly innovative decoupled electrolysis system that produces green hydrogen highly efficiently while simultaneously capturing peak energy and releasing it when needed. [1] [2] [3]

WORKING PRINCIPLE OF THE ZINC ZWISCHENSCHRITT ELECTROLYZER

The system works in sequential operation and is enabled by the high overvoltage of the hydrogen evolution at a zinc surface. During power peaks, energy is consumed through water splitting, oxygen is released and zinc is electrochemically deposited from a zincate solution. When green electricity is needed, the zinc is dissolved again, releasing the stored energy. There, green hydrogen is produced at the counter electrode (see Fig. 1). The system has a simple cell structure, a high reported system capacity, no self-discharge, does not require critical and expensive materials, is scalable, flexible with low response times, and therefore has the potential to achieve the strategic targets of the EU commission of 2 € / kg H_2 levelized costs of hydrogen (LCOH). Development is already progressing towards a prototype by STOFF2 GmbH, Germany. The system capacity, as well as the flexibility and maximum density of the charging and discharging current play a decisive role in the integration of the energy system as a buffer for green electricity and a hydrogen production plant.

EXPERIMENTAL

The experimental work involves the design and implementation of a 50 cm^2 test cell that enables both, normal operation of the system with the lowest possible voltage losses, and accurate and reproducible measurement of the anodic and cathodic partial potentials in each sequence. SEM analyses provide information about the zinc morphology under the respective conditions. The investigations and analyses address the following system properties:

- Maximum specific charging and discharging current at different temperatures (limited by the loss of overvoltage due to hydrogen evolution at the zinc surface)
- Influence of zinc morphology due to load cycling
- Maximum capacity of the zinc layer and the required optimal operating conditions
- Electrical efficiencies of the system under the tested operating conditions.

Furthermore, cost forecasts (CAPEX, OPEX, power OPEX) and the LCOH for the large-scale system are provided. Based on the results, optimized application scenarios can be created in terms of plant capacity and operating conditions. The clear application goal of the ZZE is always to store green electricity when the price of green electricity is low or even negative due to surplus production, and to supply the electricity when demand and prices are high, to keep power OPEX as low as possible, which has a direct impact on the costs of the green hydrogen produced.

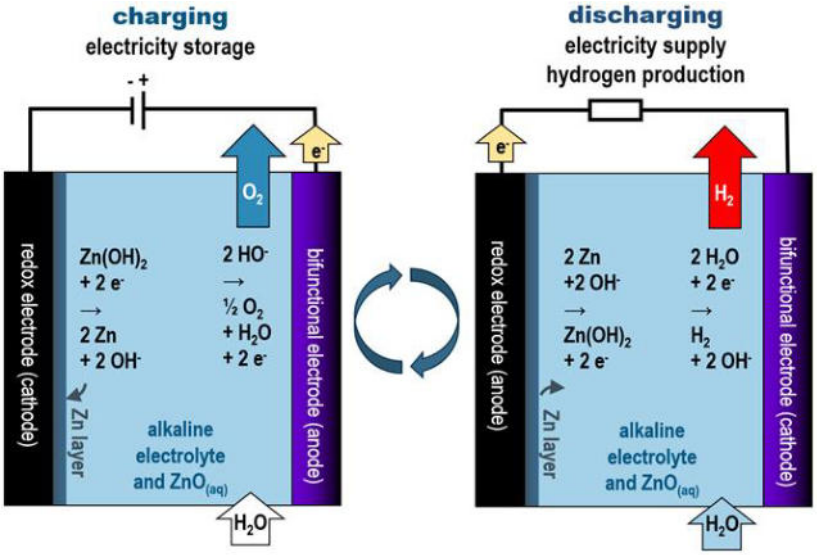


Fig. 1: Principle of the Zinc Zwischenschritt Electrolyzer and the reactions taking place during the charge and discharge sequence.

REFERENCES

[1] Hahn, R., Rosenfeld, O., Markheim C., Schamel, A. Lifetime of the Gas Evolution Electrode of the Zn-H2 Storage System. Fuel Cells 2024: e202300209. https://doi.org/10.1002/fuce.202300209.

[2] Horri, B.A., Choolaei, M., Chaudhry, A., Qaalib, H. A highly efficient hydrogen generation electrolysis system using alkaline zinc hydroxide solution. Int J Hydrogen Energy 2019;44:72-81. https://doi.org/10.1016/j.ijhydene.2018.03.048.

[3] Vila, D., Hornberger. E., Toigo, C. Machine learning based state-of-charge prediction of electrochemical green hydrogen production: Zink-Zwischenschritt-Elektrolyseur (ZZE). Energy and AI 2024;16:100355. https://doi.org/10.1016/j.egyai.2024.100355.

CONFERENCE TOPIC

1. Technologies and Systems for Buildings, Industry, Districts, Cities and Regions
   1.09. Hydrogen and Green Gas in Integrated Energy Systems

METHANE PYROLYSIS AND DRY REFORMING IN A LIQUID METAL BUBBLE COLUMN REACTOR – PROCESS PERFORMANCE AND CARBON CHARACTERIZATION

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SUMMARY

This work presents experimental investigations on methane pyrolysis and dry reforming in a liquid metal bubble column reactor operated at high temperatures (950 – 1200 °C). The reactor concept enables continuous operation under carbon-forming conditions and facilitates the production of carbon nano powder alongside hydrogen or syngas. Comprehensive gas-phase analysis and evaluation provide insights into process performance. Additionally, the solid carbon formed during operation was systematically characterized, revealing a range of nanostructures depending on the reaction conditions. These findings contribute to a deeper understanding of carbon formation mechanisms and support the assessment of its potential for industrial applications, thereby enhancing the economic viability of the process.

INTRODUCTION

Methane pyrolysis (eq. 1) is a promising route for producing CO_2-neutral hydrogen from natural gas and has been intensively studied in recent years. Key challenges include the high temperatures required (~1000 °C for non-catalytic decomposition), uniform energy supply for the endothermic reaction, and effective management of solid carbon formation to prevent coking inside of the reactor.

$$CH_4(g) \rightarrow C\,(s) + 2\,H_2(g) \qquad \Delta H_R^0 = 75\ \text{kJ/mol} \qquad \text{(eq. 1)}$$

To address these challenges, one of the proposed reactor concepts is a liquid metal bubble column reactor. This approach has been under investigation for several years and offers distinct advantages in terms of heat management and carbon handling. At the Karlsruhe Liquid Metal Laboratory (KALLA), extensive research has been conducted by Geißler et al. [1], Plevan et al. [2], Hofberger et al. [3], and Uhlenbruck et al. [4] contributing significantly to the development and understanding of this technology. The continuously operable process enables the formation of nanoscale carbonaceous powder, which is generated both in the gas phase of the rising bubbles and at the gas–metal interface. Due to the density difference, the carbon powder is released at the top of the liquid column. In contrast to conventional gas-phase reactors, deposition on heated walls is effectively suppressed by the liquid metal, allowing for stable long-term operation and improved carbon handling.
Recent research has increasingly focused on dry reforming of methane (Eq. 2), a reaction that has long been constrained by severe coking due to solid carbon formation via methane pyrolysis. The use of liquid metal-based reactor systems presents new opportunities for operating at elevated temperatures and with feed gas compositions containing a molar excess of CH_4, where carbon formation is thermodynamically favoured.

$$CH_4(g) + CO_2\,(g) \rightleftharpoons 2\,H_2(g) + 2\,CO\,(g) \qquad \Delta H_R^0 = 247\ \text{kJ/mol} \qquad \text{(eq. 2)}$$
$$H_2(g) + CO_2\,(g) \rightleftharpoons H_2O(g) + CO\,(g) \qquad \Delta H_R^0 = 41\ \text{kJ/mol} \qquad \text{(eq. 3)}$$
$$C\,(s) + CO_2\,(g) \rightleftharpoons 2\,CO\,(g) \qquad \Delta H_R^0 = 172\ \text{kJ/mol} \qquad \text{(eq. 4)}$$

Through the interplay of thermodynamic equilibria involving dry reforming, the reverse water–gas shift reaction (Eq. 3), and the Boudouard reaction (Eq. 4), the syngas composition (H_2/CO ratio) can be tuned by adjusting the CH_4/CO_2 ratio in the feed. This flexibility is particularly valuable for applications requiring customized syngas mixtures and is made possible by the stable operation of liquid metal reactors, even under carbon-forming conditions.
Current research focuses not only on optimizing process performance of methane pyrolysis and dry reforming with respect to gas-phase composition, but also on investigating the properties of the resulting solid carbon. Despite its relevance for the overall economic viability of the process, the characteristics of the carbon product remain poorly understood and have received limited attention to date.

PROCESS PERFORMANCE

Systematic experiments were conducted at the Karlsruhe Liquid Metal Laboratory (KALLA) using a 1 m high liquid tin bubble column reactor operated at temperatures ranging from 950 °C to 1200 °C. Reaction engineering parameters such as conversion and selectivity were analysed to evaluate the performance of both methane pyrolysis and dry reforming under various operating conditions. A comprehensive gas-phase analysis was performed using gas chromatography (GC) and mass spectrometry (MS), enabling detailed insight into the composition of the reaction products and the influence of temperature and feed gas ratios on syngas formation.

CHARACTERIZATION OF THE SOLID CARBON

The fine powdered carbon was collected from the reactor head and broadly characterized by imaging analysis (e.g., SEM, TEM), spectroscopic analysis (e.g., Raman, XPS) and macroscopic analyses (e.g., CHN).
Previous work by Uhlenbruck et al. [5] on the pyrolysis of methane have shown that under mild experimental conditions (low temperature and low methane concentration) mainly pyrolytic carbon sheets are formed. These show a mixture of amorphous parts and nanocrystalline graphite, are very thin but have diameters of up to several hundred nanometres. As the reaction temperature increases, carbon (nano-)onions (CNOs) also form and, at high temperatures and methane concentrations, mainly soot particles and other aggregates are found.
Evaluating the usability of pyrolytically produced carbon in potential applications fills a significant knowledge gap in the field of methane pyrolysis. Such results in turn support the assessment of economic and environmental benefits of the technology.

REFERENCES

[1] Plevan, M., et al., (2015), Thermal cracking of methane in a liquid metal bubble column reactor: Experiments and kinetic analysis. International Journal of Hydrogen Energy, 40(25), 8020–8033. Elsevier, Amsterdam, Netherlands
[2] Geißler, T., et al., (2016), Hydrogen production via methane pyrolysis in a liquid metal bubble column reactor with a packed bed. Chemical Engineering Journal, 299, 192–200. Elsevier, Amsterdam, Netherlands.
[3] Hofberger, C., et al., (2024), Technical Aspects of Natural Gas Pyrolysis in Liquid Metal Bubble Column Reactors. Energy Technology, Wiley-VCH, Weinheim, Germany
[4] Uhlenbruck, N., et al., (2024), A Carbon Capture and Utilization Process for the Production of Solid Carbon Materials from Atmospheric CO_2 – Part 1: Process Performance, ChemSusChem (Wiley-VCH GmbH)
[5] Uhlenbruck, N., et al., (2024), A Carbon Capture and Utilization Process for the Production of Solid Carbon Materials from Atmospheric CO_2 – Part 2: Carbon Characterization, ChemSusChem (Wiley-VCH GmbH)

CONFERENCE TOPIC

This abstract refers to conference topic 1.11. Net zero/negative Emissions in the Industry including CCUS

ENERGY TRANSITION AT ALWERA AG

CASCADED HEAT PUMP SYSTEM AND EXPANSION OF PV INSTALLATIONS

In 2023, the "Energy Transition ALWERA" project was launched at the Wollsdorf production site (Alwera AG and Estyria Naturprodukte GmbH). As a first step toward achieving energy self-sufficiency by 2030, a central heat pump system with cascaded heat pumps was installed and the expansion of photovoltaic (PV) systems at multiple locations was implemented. This initiative, significantly increased the share of self-generated electricity and drastically reduced dependence on natural gas and heating oil.

The aim for ALWERA AG and Estyria Naturprodukte GmbH is to position themselves as pioneering companies in sustainability and energy innovation, while reducing over-reliance on fossil fuels. The innovative concept enables simultaneous use of thermal heating and cooling energy for space and process heating, as well for cold warehouses. This reduces the overall primary energy demand, which is further lowered by replacing gas with more efficient use of electricity via heat pumps. The result: greater thermal energy output and dual use of heating and cooling energy.

Water-to-water heat pumps replace natural gas in drying systems for commercial goods and seeds with a hot water heating system. Fossil fuels are also substituted in space heating and hot water generation for office buildings, production halls, and warehouses. The cooling energy generated during heat production is repurposed for cold warehouses and excess cooling energy is discharged into the environment via air-to-water heat pumps. The heat pump system is powered by the company's own PV system and 100% green electricity.

This system reduces emissions caused by natural gas and heating oil usage and improve the ecological footprint. The project also enhances the site's attractiveness to employees by positioning the company as a role model enterprise.

Local sourcing is very important for ALWERA AG, therefore most of the implementation was carried out by companies from Styria respectively Austria.

PROJECT SCOPE AND IMPLEMENTATION ACTIVITIES

- Installation of cascaded heat pumps for centralized thermal energy supply at the Wollsdorf site
- Installation of necessary district heating and cooling pipelines between plant one and two
- Replacement of direct-fired warm air generators in drying systems (plant two) with air/water heat exchangers
- Replacement of the gas boiler in plant one
- Replacement of the gas boiler in plant two and the oil boiler in the accounting/IT office building with district heating transfer stations
- Replacement of existing decentralized cooling systems (brine circuit) with the new heat pump system
- Expansion of PV systems at various sites (approx. 1.5 MWp)

TECHNICAL SPECIFICATIONS

Maximum supply temperatures of approx. 75°C and drying air temperatures of 60°C, makes heat pump systems a viable solution for the process requirements of ALWERA AG. Water-to-water heat pumps generate the required thermal heating energy, while the resulting cooling energy is used for cold storage. Excess cooling energy is discharged via air heat pumps (cascaded configuration). The project includes

the construction of an internal district heating/cooling network with buffers, pumps, and modern control systems.

Heat pump performance data

- Total heating capacity at 75°C: 4.800kW
- Total cooling capacity at 7°C: 2.600kW
- Electrical connection capacity: 2.550kW

PV system expansion at three locations

- Wollsdorf: 910 kWp
- Herzogenburg: 440 kWp
- Paldau: 150 kWp

Total 1.500 kWp

Estimated annual savings (based on previous consumption)

- Substitution of approx. 4,400,000 kWh of natural gas
- Substitution of approx. 30,000 kWh of heating oil
- Reduction of CO_2 emissions by approx. 1,100 tons
- Increase in self-generated electricity from PV systems by approx. 1,650 MWh

PERCEPTION OF INDUSTRIAL SYMBIOSIS AND CARBON MANAGEMENT IN AUSTRIA

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SUMMARY

Cooperation, particularly in the areas of electricity, heat, and CO_2 management, can make a decisive contribution to increasing energy efficiency and reducing emissions. As part of Austria's participation in IEA IETS Task 21, a national online survey on cross-company energy cooperation and industrial carbon management was conducted. It aimed at experts from institutions like the Federation of Austrian Industries and its regional offices, the federal and state chambers of commerce, and the location promotion agencies of the Austrian states, i.e. their representatives and advisors who are in contact with companies. For newly relocating companies, securing supply and connections is a priority. Similarly, affordable supply as well as green supply, are high priorities for established companies. For both, cooperation topics are discussed less frequently than other energy and carbon topics. Half of the consultants stated that local collaborations on energy or CO_2 are not yet a relevant topic. There is interest in CO_2 management and carbon capture among companies, even if it plays a minor role compared to other energy issues; uncertainty about regulatory and economic aspects is hindering greater engagement.

INTRODUCTION

As part of Austria's participation in the second phase of "IEA IETS Task 21: Net-zero Industrial Systems in a Circular Economy," we were investigating how industrial symbiosis and carbon management can contribute to a more sustainable industry. The "Circular Carbon" subtask focuses on the technical integration of carbon capture and utilization (CCU) into industrial systems. The "Industrial Symbiosis" subtask analyses how companies can use resources more efficiently and collectively save energy through cooperation to make industrial processes more sustainable. To do so, a national survey on cross-company energy cooperation and industrial carbon management was conducted. The aim of the survey was to determine the current status and prevalence of such approaches in Austria. Cooperation, particularly in the areas of electricity, heat, and CO_2 management, can make a decisive contribution to increasing energy efficiency and reducing emissions. Since this type of cooperation is still relatively rare, the study investigated the status quo in practice and good practices how regional institutions can initiate and support such cooperation.

METHODS

The approach was planned as a survey among companies. The rapidly increasing relevance of CCU and CCS and the recently conducted surveys on it, e.g., from the CaCTUS project, led to the decision to make an online survey, which was conducted in June 2024 and aimed at experts from institutions i.e. their representatives and advisors who are in contact with companies. Addressed institutions are the Federation of Austrian Industries (IV) and its regional offices, the federal and state chambers of commerce (WKO), and the location promotion agencies of the Austrian states. Their experts advise companies in the areas of energy and CO_2 management, as well as in site selection and site development. The underlying assumption is that these institutional experts are aware of the needs and concerns through their networks; their practical knowledge allows them to provide a comprehensive picture of the current status and requirements in Austria. The questionnaire was set up online, and participants

were then personally invited to participate or encouraged through existing contacts. The questions were categorised as follows: (i) Personal information, institution, and internal responsibilities, (ii) Topics addressed in meetings with companies, (iii) Carbon management, (iv) Tools and methods for industrial symbiosis, (v) Best practice examples. A total of 10 responses were received from the various institutions. This is entirely in line with expectations, given the maximum number of approximately 30 institutions in Austria.

RESULTS

The survey clearly shows that while cooperation between companies is an important lever for energy efficiency and climate neutrality, its practical implementation varies greatly. Traditional local energy communities such as shared PV are more common among local companies and are actively supported by consultants. More complex forms of industrial symbiosis, such as shared infrastructure, CO_2 capture, or inter-company cycles, are still rare and associated with significant hurdles (legal, technical, and financial). Only a few consulting institutions have specialised tools to promote such cooperation; instead, partnerships often develop through networks, cluster events, or pioneering projects. Overall, the results show that simple energy cooperation is on the rise, but more framework conditions, tools, and best-practice models are needed for advanced symbiotic approaches.

- Newly establishing companies are focusing on a stable and affordable energy supply.
- Established companies have a broader interest in sustainable solutions such as PV, renewable gases, and carbon neutrality.
- For both, cooperation topics are discussed less frequently than other energy and carbon topics. Half of the consultants stated that local collaborations on energy or CO_2 are not yet a relevant topic.
- Collaborations and tools to promote industrial symbiosis are underdeveloped – but successful best practice examples demonstrate the potential.

Consultants report that companies are actively addressing CO_2 capture and state that they consider it essential for the decarbonisation of certain sectors. At the same time, implementation remains hesitant, as legal uncertainties, high investment costs, and considerable energy requirements act as barriers. While individual pioneers are already implementing demonstrators, widespread adoption is not yet in sight. Many companies are closely monitoring technological developments and view CCU and CCS as essential in the long term, but are unwilling to invest until stable framework conditions, mature processes, and clear economic benefits are in place.

- CO_2 management and carbon capture still play a minor role – despite existing interest, uncertainty about regulatory and economic aspects is hindering greater engagement.

REFERENCES

Moser, Rodin, Pflügl (2024) Results of the survey "Perceptions of Industrial Symbiosis and Carbon Management in Austria." Report within the framework of IEA IETS TASK XXI, September 2024, Web: https://energieinstitut-linz.at/wp-content/uploads/2025/02/Umfrage-Industrielle-Symbiose-und-Carbon-Management-in-Oesterreich.pdf.

CONFERENCE TOPIC

This Abstract refers to Conference Topics 1.10 & 1.11.

DEVELOPING EFFICIENT PIT THERMAL ENERGY STORAGES FOR DISTRICT HEATING - STORAGE LABORATORY AND SIMULATION WORK

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SUMMARY

The next generation of Pit Thermal Energy Storages (PTES) shall permanently meet the requirements of the European district heating industry. The presented research is therefore working in particular on topics such as advancing materials for higher long-term durability at 95°C storage temperatures, inexpensive construction and operating methods, well-function and long-lasting floating covers, reliable and simple operation monitoring, and support of the market deployment through evaluated simulation models and simplified tools.

INTRODUCTION

As the decarbonization of district heating is important to meet the climate goals, large-scale thermal energy storages play a key role in enabling the integration of renewable heat sources and improving the flexibility of the systems. Pit Thermal Energy Storages (PTES) offer a cost-effective solution for short- and long-term heat storage. Their simple construction and scalability make them attractive for widespread deployment. Most of the existing PTES were built together with large-scale solar thermal installations integrated in DH systems in Denmark (Tschopp, et al., 2020) and some smaller ones in Germany (Solites, 2022). Currently around 17 PTES were build. Europe hosts a growing number of PTES, with Denmark leading in operational installations and several smaller projects underway in countries like Germany, Austria, France, and Serbia. The sizes range of some 100 m³ to more than 400,000 m³. Based on current planning and decarbonization goals, experts estimate that over 2,000 large PTES systems will be needed across Europe to fully decarbonize district heating networks (TREASURE, 2025). This indicates a strong market potential and a significant scaling-up of PTES technology in the coming years.

Despite extensive operational experience, several technical and scientific challenges remain, including the long-term durability of materials at temperatures up to 95°C, optimization of the floating cover regarding vapor transmission, stability and detection of leaks.

The public research project “Efficient Pit” (2021 to 2027) addresses these challenges with the goal of developing a new generation of PTES that meets the long-term requirements of the European district heating industry. Key objectives include the development of a novel high-temperature polymeric liner, improved designs for insulation and cover structures, scalable construction methods for storage volumes up to 500,000 m³, and a validated conceptual design tool for simple preliminary designs of large-volume PTES.

INNOVATIONS TESTED IN A STORAGE LABORATORY

With the construction of a storage laboratory with two PTES (2,000 and 3,000 m³), the project partners have a unique opportunity to test construction methods. The laboratory PTES will be finished in autumn 2025 and will be operated with industrial waste heat from the Solmax production of high-temperature polyethylene liners in Rechlin, Germany (see figure 1).

Figure 1: Pit Thermal Energy Storage laboratory in Rechlin, Germany (Source: Solmax)

So far, there are several innovations realized in the storage laboratory compared to existing PTES:

- Steep embankment with soil with 34° (southern pit) and reinforced soil with 70° (northern pit).



- Penetration structures made of polyethylene instead of concrete to ensure safety at these sensitive points.
- Different types of thermal insulation at the walls and the bottoms of both PTES. This allows the thermal insulation to be tested under real conditions.
- Integration of a fibreoptic leak detection system
- Lining with the latest generation of protective layers and high-temperature-resistant sealing geomembranes, which were specially developed within the research project.
- Diffusers made of polypropylene to avoid corrosion problems with steel. Water treatment can be simplified, saving costs and time during filling.

In order to evaluate the materials and construction designs under real conditions a comprehensive measurement concept with 175 sensors was developed and implemented. Ten PT100 sensors on different height positions and heat flux sensors were installed in the soil of each storage wall in order to investigate different insulation materials and their influence on thermal interaction with the subsoil. In some cases, individual walls were equipped with special measurement technology to investigate specific correlations and effects between the subsoil and the storage. For example specific soil-moisture and heat-flux measurement technology were installed in order to better understand moisture transport and the resulting heat transport processes in the ground and the investigation of possible drying out of the embankment during operation. Furthermore, comprehensive temperature measurements of a wall cross-section using a fibre optic temperature measurement system (Raman-Scattering) is being presented in the context of PTES for the first time. The special measurement methods mentioned above can be used, for example, to validate simulation models for thermal interaction with the ground in the future.
Another key element of the project is the measurement of different insulation materials and lid constructions with regard to heat-coupled mass transport. One of the two lid constructions was divided into four segments. Each segment contains a spatially separated measuring field in which extensive moisture, temperature, and heat flux measurement devices are installed. The aim of the investigation is to validate a calculation tool developed for the heat-coupled mass transport in order to better predict possible moisture accumulation and associated heat losses in future lid constructions.

In addition, the radial diffuser is also being examined for the first time. The task of a radial diffuser is to charge the PTES with as little mixing as possible of the inflowing water into the existing temperature stratification of the storage. The functionality of these components has previously only been examined on a laboratory scale and is now to be examined in real operation for the first time.
A total of 13 fibre optic temperature measurement probes were installed on and around the diffuser for this purpose. The measurement technology involves fibre optic temperature measurement based on Rayleigh scattering. This allows temperature measurements of the inflowing water at the diffuser to be resolved with millimeter precision. This means that asymmetries and the mixing behavior of the diffuser can be examined for the first time in real operation conditions. Existing CFD models are to be validated using the generated data.
Another innovation among the monitoring concept is the comparison between two different leak detection systems. For the first time, a DTS hybrid system is being used for leak detection and temperature monitoring of the storage walls and lid. A total of 1375 meters of heatable fiber optic cable was installed. Compared to point measurements, the DTS cable allows continuous temperature measurement, so that a surface temperature distribution can be visualized for each storage wall and section of the storage.

FURTHER PLANNED ACTIVITIES

1. Operation and measurement campaigns of the storage laboratory and evaluation of the experiences and results
2. At the international level, the developments are being disseminated through participation in the IEA ES Task 39 LTES for DH (Large Thermal Energy Storage for District Heating) (IEA ES Task 39, 2022) and the follow up IEA ES Task 45 (Accelerating the Uptake of Large Thermal Energy Storages) (IEA ES Task 45, 2024).
3. Publication of a conceptual design tool for simple preliminary designs of large-volume PTES.
4. Validation of a proprietary calculation tool for a better understanding of heat-coupled mass transfer in covers of the lid construction of PTES. Validation of the calculation tool with comprehensive measurement technology using real data from laboratory storage.
5. Investigation of the flow behaviour of radial diffusers using a fibre optic temperature measurement technique based on Rayleigh scattering for the first time with accompanying CFD simulations for diffuser optimization.

EXPECTED RESULTS

Development of the next generation of pit thermal energy storage, which permanently meets the requirements of the European district heating network industry.
The presentation will give a short market overview of realized large-scale PTES and current needs on research for large-scale PTES in district heating based on results of the existing PTES. Main focus is the research activities and results in the research project described here, which will show design and innovation aspects of the execution of the storage laboratories like:

- Experience from the construction of the storage laboratory and measurement data of its operation
- Heat recovery of the production
- Storage geometries e.g. 70° inclination
- Comparison of innovative insulation concepts of the storage to the subsoil
- Novel high temperature resistant sealing and protecting materials
- Polymer penetrating structures
- Polymer loading and unloading pipes incl. diffusers
- Novel leakage monitoring systems for the pit and lid
- Examples of the simulations e.g. of the outflow behavior at the diffusers will be presented
- Comprehensive monitoring system in the surrounding subsoil for evaluating different wall structures, investigation of the moisture transfer in the subsoil and validating multiple calculation tools for interaction with the surrounding soil in FeFlow and improving system based models in TRNSYS.

- High-resolution temperature profiles using innovative fibre optic temperature measurement for evaluating radial diffusers and options for validating CFD tools for further optimization of diffusers.

The project has already been presented (ISEC, 2024) and is now at a more advanced stage, so that the described results can be shown.

REFERENCES

IEA ES Task 39, (2022), Large Thermal Energy Storages for District Heating. [Online] 28 August 2025. https://iea-es.org/annex-39/.

IEA ES Task 45, (2024), Accelerating the Uptake of Large Thermal Energy Storages. [Online] 28 August 2025. https://iea-es.org/task-45/.

ISEC (2024), Conference Proceedings page 172-174. [Online] 28.08.2025. https://www.aee-intec-events.at/past-conferences/review-isec-2024.html

Solites, (2022), Saisonalspeicher. [Online] 8 April 2022. http://www.saisonalspeicher.de/.

TREASURE (2025). [Online] 28.08.2025. https://www.treasure-project.eu/

Tschopp, D., et al., (2020), Large-scale solar thermal systems in leading countries: A review and comparative study of Denmark, China, Germany and Austria. [Online] 2020. https://doi.org/10.1016/j.apenergy.2020.114997.

CONFERENCE TOPIC

Emerging heat and cold storage
Future District Heating and Cooling Solutions

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IMPACT OF HYGOTHERMAL PROPERTIES OF MATERIALS ON THE ENERGY EFFICIENCY OF VENTILATION UNITS

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SUMMARY

The paper investigates the impact of the hygrothermal properties of building materials on the energy consumption of ventilation systems for summer humidity regulation in office spaces. Using EnergyPlus simulations, the study compares timber, reinforced concrete, and brick constructions, focusing on their hygroscopic properties and ability to buffer indoor humidity. Results show that timber construction reduces energy consumption by approximately 3% compared to reinforced concrete, which has lower moisture absorption. The findings emphasize the potential of hygroscopic materials to passively regulate humidity, reducing the load on ventilation systems and enhancing energy efficiency. The study highlights the relevance of material selection in sustainable building design and higher humidity buffering materials could reveal even greater energy-saving potential. These insights contribute to the development of energy-efficient and climate-friendly construction practices and thus use resources more efficient.

INTRODUCTION

The building sector takes a significant portion of global energy use and carbon emissions mainly due to the heating and cooling demand (Europäisches Parlament, 2024). Ventilation systems used for dehumidification by heating and cooling of the fresh air during summer, contribute substantially to this energy demand. The study aims to investigate whether the strategic selection of building materials can reduce this energy consumption. By focusing on the hygroscopic properties of materials, the research seeks to identify passive mechanisms for moisture regulation that can complement mechanical systems, thereby enhancing energy efficiency. The study examines the extent to which different construction materials impact the energy consumption of ventilation systems for summer humidity control.

METHODOLOGY

The study employs a hygrothermal simulation using EnergyPlus software, a widely recognized tool for building energy analysis. The simulation framework was designed to compare the main three construction types as used in Austria —timber, reinforced concrete, and brick—under identical conditions (Statistisches Bundesamt, 2025). A standardized office space with defined cooling and humidity loads was modeled to ensure consistency and comparability across the variants. The simulation focused on evaluating the energy required for dehumidifying supply air, with particular attention to the materials' ability to absorb and release moisture. The EnergyPlus Effective Moisture Penetration Depth (EMPD) model was used to simulate the moisture-buffering effects of the materials. While this model provides a simplified representation, it offers valuable insights into the proportion between material properties and energy consumption.

RESULTS

The simulation results demonstrate that timber construction, due to its superior hygroscopic properties, reduces the energy consumption of the ventilation system for humidity regulation by approximately 3%. Reinforced concrete, with its lower moisture absorption capacity, results in higher energy consumption, while brick construction falls between these two as seen in Figure 1.



FIGURE 30: ENERGY DEMAND OF THE VENTILATION UNIT

By using wood construction compared to concrete construction, the energy consumption of the ventilation unit can be reduced by 3% while by using brick construction it can be reduced by 2.5%.
These findings highlight the potential of hygroscopic materials to passively regulate indoor humidity, thereby reducing the operational load on mechanical systems. The study also highlights the importance of ventilation units in regard to the indoor humidity while keeping the energy demand at a low level and support ventilation units during times of high loads by choosing different kinds of building materials.

CONCLUSION

In conclusion, the thesis underscores the importance of material selection in optimizing the energy efficiency of ventilation systems. By leveraging the moisture-buffering capabilities of materials like timber, buildings can achieve significant energy savings while maintaining indoor comfort. The study highlights the need for further research using advanced simulation models to refine these findings and explore additional opportunities for energy-efficient building design. The insights gained from this research contribute to the development of sustainable construction practices and support the transition toward a more energy-efficient built environment.

REFERENCES

Europäisches Parlament. (2024). *RICHTLINIE (EU) 2024/1275 DES EUROPÄISCHEN PARLAMENTS UND DES RATES* (S. 7) [Amtsblatt]. Europäische Union. https://eur-lex.europa.eu/eli/dir/2024/1275/oj
Statistisches Bundesamt. (2025). *Baugenehmigungen im Wirtschaftsbau in Deutschland 2023*. Statista. https://de-1statista-1com-1l2m0mpkb10ba.han.technikum-wien.at/statistik/daten/studie/252743/umfrage/struktur-der-genehmigten-wirtschaftsbauten-in-deutschland/

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
Next-Generation Technologies for Renewable Energy and Resource Efficiency

ANALYSIS OF MARINE AND INDUSTRIAL CONDENSING STEAM ENGINE PERFORMANCE FOR LOW-GRADE WASTE HEAT RECOVERY

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SUMMARY

Globally, at least 3,100 thermal terawatt-hours (TWh_{th}) of feasible waste heat is currently not being captured (Hajlasz et al., 2023). Low-grade waste heat and low temperature sources are typically utilized to make electricity and mechanical power by the application of Organic Rankine Cycle (ORC) systems. However, the condensing steam engine (CE) using a naturally abundant and environmentally friendly working fluid, water, may provide the solution to fulfil the requirements of many power systems with a working temperature of as low as 100°C and atmospheric steam pressure. CEs were common in early steam engine designs and gradually became low pressure (LP) stages of higher-pressure engines as inlet temperatures and pressures increased. Results from tests of small engines built in the late 19th Century, which have been recently re-published, show a mechanical efficiency of 3.7%, with a second law efficiency of 24.7% (Muller & Howell, 2021). However, this is far from the state-of-the art of the last steam era or the potential that lies in the one ahead. The CE's adequate efficiency and non-reliance on exotic materials, combined with the lower capital, operating, and disposal costs of water bring this technology to the forefront to derive more utility from cement, steel, oil & gas, marine, and industrial thermal processes as well as utilize primary sources such as geothermal and low-grade solar thermal energy.

Keywords: Steam Engine, Condensing Engine, Thermal Efficiency, Second Law Efficiency, Waste Steam

INTRODUCTION

The use of low-grade waste heat to generate electricity and mechanical power is an endeavour engaging the minds of many in the modern scientific community. There are elaborate systems in use and more in development which often have increasing complexity and toxicity of their working fluids which may yield declining or even negative life cycle returns compared to legacy systems. A recent paper by Muller and Howell (2021) provides a comparison of Organic Rankine Cycle (ORC) and Condensing Steam Engines (CE's) of a few kW's of power or less, and shows competitive efficiencies. However, small displacement steam engines have a comparatively large amount of internal surface area to their volume, and this results in high levels of initial condensation in the cycle leading to low thermodynamic efficiency (Stumpf, 1926; Rogers, 1972). As such, small engines were typically applied only as auxiliary power in large plants where electric motors were not available and the drive reliability (such as a boiler draft blower motor) was more valuable than a more complex solution. When looking at a range of opportunities that include industrial facilities, marine propulsion Internal Combustion Engines (ICEs), marine hotel load (cruise ships, drilling platforms) ICEs, geothermal, and other sources of heat, exploring larger displacement CE designs has relevance.

ANALYSIS OF VARIOUS CES

There are two types of steam engines, a counterflow where exhaust steam retraces its path, uniflow where steam exhausts from terminal cylinder ports, and a variant of uniflow, Unaflow, where auxiliary exhaust in the cylinder head is provided (counterflow) to relieve excess compression in all or certain operating conditions.

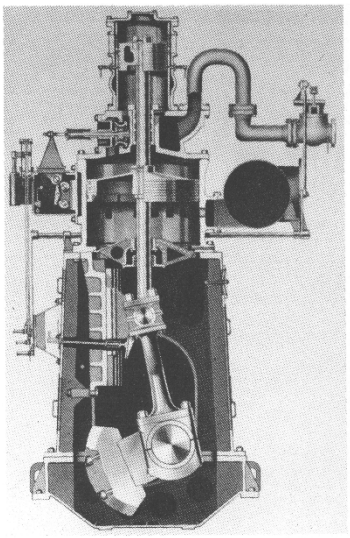


Fig. 1: Skinner Compound Unaflow Marine Steam Engine (1953)

TABLE III
U.S.S. TEXAS - TRIAL DATA.

	4 HOURS' TRIAL (b)		24 HRS' 19 KTS. TRIAL (c)		24 HRS' 12 KTS. TRIAL (d)		2 HOURS' COAL & OIL BURNING TRIAL (e)	
DATE OF TRIAL	OCT. 28, 1913		OCT. 30 & 31, 1913		OCT. 28 & 29, 1913		OCT. 31, 1913	
SPEED IN KNOTS	21.05		19.078		12.197		20.988	
DRAUGHT, MEAN ON TRIAL, FEET AND INCHES	27 - 9¼		27 - 9		27 - 8			
DISPLACEMENT, CORRESPONDING, TONS	26,250		26,230		26,130			
PRESSURES (AVERAGE):	STARBD.	PORT	STARBD.	PORT	STARBD.	PORT	STARBD.	PORT
MAIN STEAM, AT BOILERS, POUNDS GAUGE	295.6		284.9		285.5		287.4	
ENGINES, DO.	274.1	274.1	276.5	276.5	274.8	279.5	265.2	262.2
1ST REC'S., POUNDS ABSOLUTE	94.1	88.3	75.6	71.1	32.9	31.6		
2ND REC'S., DO.	27.9	25.06	19.2	18.3	11.6	8.09		
VACUUM, MAIN CONDENSERS, INCHES OF MERCURY	26.72	26.9	26.71	26.92	26.34	27.07		

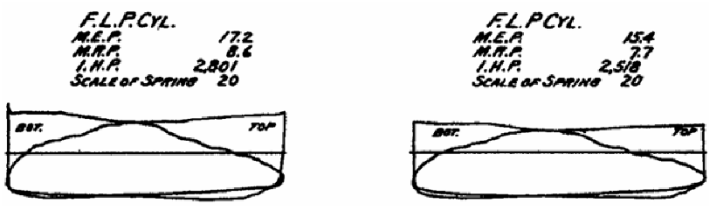


Fig. 2: U.S.S. Texas Sea Trail Data (ASNE, 1914)

There are several larger CE designs built from 1910 through the 1950's which meet the criteria of approximately 100°C inlet temperature atmospheric pressure steam. Three cases will be analysed: 1) A unique and almost forgotten standalone CE by Shuman-Haines where steam was provided by a low concentration ratio solar collector array with abundant water for condensing available; 2) Sea trial data of the LP stage of the triple expansion quad engines of Battleship Texas; 3) Sea trial data of the LP stage of the Skinner Marine Unaflow of the S.S. Spartan.

EXPECTED OUTCOME

By analysing this data, the effectiveness of the CE at greater scales is made available. It is expected that analysis of the three cases will show significantly higher efficiencies than Muller. As each of the engines have certain unique attributes, it is expected to find designs which exhibit certain advantages in efficiency and power density. The results should suggest desirable attributes for the CE to be incorporated into redevelopment of this practical and low environmental impact solution to increasing the available power to drive humanity.

REFERENCES

Hajlasz, M., Helmcke, S., Liebach, F., Schleyer, T., & Somers, K. (2023, December). *Waste not: Unlocking the potential of waste heat recovery.* McKinsey & Company. https://www.mckinsey.com/capabilities/sustainability/our-insights/waste-not-unlocking-the-potential-of-waste-heat-recovery

Muller, G. & Howell, C. (2021). Comparative analysis of ORC and condensing heat engines for low grade waste heat recovery. *Applied Engineering*, *5*(1), 7-13. https://doi.org/10.11648/j.ae.20210501.15

Rogers, H. C. B. (1972). *Chapelon: Genius of French Steam.* Ian Allan.

Stumpf, J. (1922). *The Una-flow steam-engine*. Stumpf Una-Flow Engine Company, Incorporated.

CONFERENCE TOPIC

Excess Heat and Resource Recovery from Low-Grade Sources

SIMPLIFYING DISTRICT HEATING TOPOLOGIES WITH BIDIRECTIONAL LINES FOR OPTIMAL CONTROL

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SUMMARY

This paper explores the optimal control of producer dispatch in decentralized district heating networks and the consideration of thermohydraulic constraints within the optimization formulation. It proposes methodologies for aggregating network structures to simplify optimization while addressing the challenges through decentralized production that typically imply bidirectional lines. The study applies these methods to a medium-sized district heating network in Weil am Rhein, Germany, analyzing parameters like pressure head, fluid delay time, and network losses over a 24-hour period. Findings indicate that simulation times could be reduced by up to 68%, but errors increase, especially during flow direction changes.
Keywords: District Heating, Model Predictive Control, Topology aggregation, Optimization

INTRODUCTION

The optimal control of producer dispatch within district heating networks with decentralized producers is a complex challenge that ideally involves consideration of thermohydraulic network constraints. Achieving an effective solution necessitates either the aggregation of network structures [1, 2, 3, 4] or simplification of the underlying models [5, 6]. The approach of the network topology aggregation involves reducing the number of consumers and pipes (and therefore number of constraints) while ensuring that the network parameters yield consistent results at designated design points. However, deviations from detailed models may arise at off-design points, particularly in decentralized networks characterized by bidirectional lines that can lead to flow direction switches during off-design operations. This paper explores various strategies for managing these bidirectional lines, examining whether they can be effectively aggregated without incurring significant errors. The findings aim to enhance understanding of the implications of aggregation depth on optimal control effectivity and provide insights for future research and practical applications in decentralized thermohydraulic systems.

METHODOLOGY

Existing methodologies have been developed to effectively combine the thermohydraulic behavior of various pipe segments and consumers within district heating network topologies. [1, 2, 3] However, the handling of bidirectional lines remains a critical challenge.
To address this issue, the methodology assesses the impact of discretizing bidirectional lines at various levels of detail. This assessment includes a careful selection of the design point, where the starting point of an optimization step is applied. This allows for a dynamic adjustment of aggregation depth throughout the operation of the network, ensuring that the model remains responsive to changing conditions.
The proposed methodology has been applied to a medium-sized district heating network in Weil am Rhein, Germany, which encompasses approximately 120 consumers and 10 production units. For each aggregation scenario, critical parameters such as the pressure head at each producer pump, the delay time of the fluid within the network, and network losses over a typical time horizon of 24 hours, relevant for model predictive control applications, are compared.

The findings indicate that the error becomes more pronounced during control steps that involve changes in flow direction, while the averaged deviation over all time steps is smaller. Importantly, the appropriate level of discretization for bidirectional lines is contingent upon the likelihood and frequency of flow direction changes occurring within the network. Lastly, the simulation times across different aggregation scenarios to evaluate the efficiency of the proposed methodology are compared. Simulation time could be reduced by up to 68 %.
In summary, this assessment provides valuable insights into the complexities of network aggregation in systems with bidirectional lines, paving the way for more accurate and effective control strategies. Future research objectives include transferring the results to optimization applications and investigating the solution times not only for the simulation but also for the optimization process. Furthermore, the problem could be compared using different linearized calculations of the nonlinear equations.

REFERENCES

[1] Loewen, Achim (2001): Entwicklung eines Verfahrens zur Aggregation komplexer Fernwärmenetze. Universität Dortmund, Dortmund.

[2] Pálsson, Halldór; Larsen, Helge; Bøhm, Benny; Ravn, Hans; Zhou, J. (1999): Equivalent models of district heating systems for on-line minimization of operational costs of the complete district heating system: Technical University of Denmark. Department of Energy Engineering.

[3] Falay, Basak; Schweiger, Gerald; O'Donovan, Keith; Leusbrock, Ingo (2020): Enabling large-scale dynamic simulations and reducing model complexity of district heating and cooling systems by aggregation. In: *Energy* 209, S. 118410. DOI: 10.1016/j.energy.2020.118410.

[4] Mans, Michael; Blacha, Tobias; Remmen, Peter; Müller, Dirk (2019): Automated model generation and simplification for district heating and cooling networks, S. 179–186. DOI: 10.3384/ecp19157179.

[5] Bott, Andreas; Friedrich, Pascal; Rehlich, Lea; Steinke, Florian (2021): Model Reduction for Heat Grid State Estimation, S. 1–5. DOI: 10.1109/ISGTEurope52324.2021.9640025.

[6] Giraud, L.; Merabet, M.; Baviere, R.; Vallée, M. (2017): Optimal Control of District Heating Systems using Dynamic Simulation and Mixed Integer Linear Programming. In: *Proceedings of the 12th International Modelica Conference*, S. 141–150. DOI: 10.3384/ecp17132141.

CONFERENCE TOPIC

This abstract refers to the following Conference Topics:

- 1.05. Digitalization for Smart, Resilient Energy Systems
- 1.08. Future District Heating and Cooling Solutions

CO_2 ELECTROLYSIS UTILIZING CO_2-CAPTURED FROM FLUE GAS TO CLOSE THE CARBON LOOP IN THE STEEL INDUSTRY AND BEYOND

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SUMMARY

CO_2 electrolysis emerges as a promising technology to reduce greenhouse gas emissions via converting CO_2 with renewable electricity from industrial point sources to valuable chemicals and fuels. So far, the technology is mostly tested using pure and concentrated CO_2 feeds at lab scale. In this study, we show the pioneering combination of amine-based CO_2 captured from the power plant of an integrated steel mill and CO_2 electrolysis to produce CO at TRL 6. The CO is re-utilized in the steel industry demonstrating a closed carbon loop. This work presents an important step towards industrial implementation of the CO_2 electrolysis technology and shows a possible CCU value chain.
Keywords: CCU, CO_2 conversion, decarbonization, CO_2 electrolysis, flue gas CO_2 capture

INTRODUCTION

Global warming driven by industrial CO_2 emissions has become a critical societal issue, demanding technological innovation to mitigate and potentially reverse its impact. The global steel industry alone accounts with 2.6 Gt CO_2 for 7% of human-made greenhouse gas emissions and despite electrification and replacement of fossil-derived energy carriers by green hydrogen, carbon will continue to have an important role in the energy-intensive industry. Carbon capture and utilization (CCU) strategies can mitigate those hard-to-abate emissions and at the same time act as carbon source to produce chemicals and fuels giving CO_2 an economic value.

To date, solely a small portion of the industrial flue gas is captured & utilized and many of these technologies are still under research at lower TRL. There are several ongoing research activities to either capture or convert CO_2 from flue gas (e.g. EU projects CESAR, CACHET, eCOCO2, MegaSyn, SolarCO2Value, Carbon2Chem) [1], but demonstrations along the whole CCU value chain at TRL 5-7 are rare. Among emerging CO_2 conversion technologies, CO_2 electrolysis is a particular promising strategy, since its only additional inputs are (renewable) electricity and water. CO_2 can be converted into a variety of valuable products with industrial relevance such as CO/syngas, methane, ethylene or ethanol and product selectivity is achieved through an appropriate catalyst material and electrode design. To avoid limited CO_2 supply to the catalyst, zero-gap cell designs and gas diffusion electrodes, as-known from water electrolysis, are successfully being implemented. However, this technology was up to now primarily tested using pure CO_2 streams in lab environments and not yet evaluated with CO_2

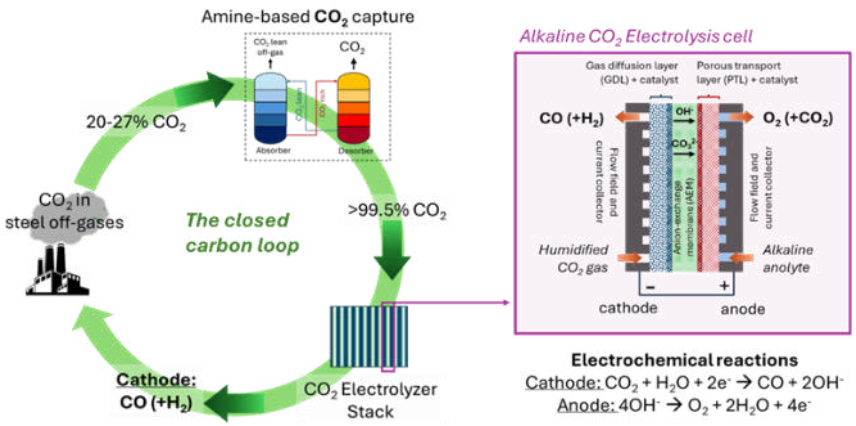


FIGURE 31 PROCESS SCHEMATIC OF CO_2-CAPTURED FROM STEEL FLUE GAS AND ALKALINE ZERO-GAP CO_2 ELECTROLYSIS TO CO

captured from industrial flue gas and its impurities.

METHODOLOGY

In this contribution the integration of amine-based CO_2 captured from the power plant of an integrated steel mill with a pilot-plant CO_2 electrolysis unit to produce CO at TRL 6 and its re-utilization in the steel industry is demonstrated. The overall process methodology is shown in **Figure 1.** CO_2 is captured by amine scrubbing at a pilot-scale of up to 800 kg/day using optimized amine solvent compositions and process parameters to provide reliable feeds of >99.5% CO_2 at low energy consumption. The CO_2 from the amine scrubber is directly fed to an alkaline zero-gap CO_2 electrolysis cell that uses Ag-based catalysts to achieve high selectivity to CO. With a 60kW cell stack and electrode sizes of 2500cm^2 up to 1 tonne CO_2/day can be converted to CO at near atmospheric pressures and low temperatures <70°C.

RESULTS

Key parameters of the CO_2 electrolysis are energy input per kg product (e.g. kWh/kg CO obtained) and the throughput related to the current density (mA/cm^2), product composition/selectivity (Faraday efficiency FE%) and single-pass conversion efficiency (SPC). In addition, material and process durability are vital towards industrial implementation. Product composition defines downstream purification and applications.
Initial technology assessment was done using pure CO_2 in the labs at eChemicles. At 400-600mA/cm^2 a FE% >90% to CO and a SPC of >30% was demonstrated [2].
In this work the containerized CO_2 electrolysis unit and the cell stack (see **Figure 2)** are for the first time operated using real flue gas streams from the steel industry captured via amine scrubbing. The impact of different process parameters such as CO_2 flow rate, current density and pressure on the product composition, process efficiency and stability are assessed. The findings presented facilitate a preliminary evaluation of the synergistic integration potential of the combined technologies within the framework of a circular carbon economy in the steel industry.

AKNOWLEDGEMENT

This project is funded by the ZEUS (**Z**ero **E**mission thro**U**gh **S**ector Coupling) FFG (Project No. FO999903855) project from the Energy Fund and is being carried out as part of the Energy Research Program 2022.



FIGURE 2: CONTAINERIZED CO_2 ELECTROLYSIS UNIT (LEFT) WITH CELL STACK (RIGHT)

REFERENCES

[1] https://cordis.europa.eu/project/id/213569/reporting, https://cordis.europa.eu/project/id/241342/reporting , https://ecocoo.eu/ , https://www.megasyn.eu/ , https://solarco2value.eu/ https://www.thyssenkrupp-carbon2chem.com/

[2] Endrődi, B. *et al.* (2020) 'High carbonate ion conductance of a robust PiperION membrane allows industrial current density and conversion in a zero-gap carbon dioxide electrolyzer cell', *Energy & Environmental Science*, 13(11), pp. 4098–4105. Available at: https://doi.org/10.1039/D0EE02589E.

CONFERENCE TOPICS

Net-zero/negative Emissions in the Industry including CCUS, Circular Economy Strategies for the Energy Transition, Solar-to-X Technologies for Fuels and Chemicals

UNLOCKING ATES: SCALING SUSTAINBLE HEATING AND COOLING ACROSS EUROPE

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SUMMARY

Aquifer Thermal Energy Storage (ATES) is a highly efficient and scalable technology that can reduce CO_2 emissions from building heating and cooling by more than 50%. The Netherlands has already demonstrated large-scale success, supported by favourable geological conditions, clear regulations, and strong cooperation between public and private stakeholders. Beyond its traditional use, ATES is increasingly applied for large-scale heat storage and grid balancing, offering flexibility to the wider energy system. For broader adoption across Europe, challenges remain in establishing clear legal frameworks, developing viable financing models, and overcoming the innovation gap. By fostering international collaboration, ATES can become a cornerstone of Europe's sustainable energy transition.

INTRODUCTION

In the transition to sustainable energy, subsurface energy plays a crucial role. In dense urban areas, options for wind and large-scale solar are limited, while district heating networks face technical, financial, and organizational challenges. Ground source heat pumps are already common in Europe due to their reliability and adaptability, but Aquifer Thermal Energy Storage (ATES) offers even greater efficiency and is ideal for large-scale applications thanks to its small spatial footprint.
In the Netherlands, ATES is a mature and widely used technology, with thousands of systems in operation. Elsewhere in Europe and globally, adoption remains limited, despite the potential to cut fossil fuel use and reduce CO_2 emissions from building heating and cooling by at least 50%. The key question is how to scale up ATES across Europe and which factors will drive its broader deployment.

WHAT IS ATES?

ATES enables sustainable heating and cooling of buildings by storing thermal energy in aquifers. In summer, cold groundwater is extracted, passed through a heat exchanger, and used to cool the building. Simultaneously, the building's heat is transferred to the aquifer and stored in a warm well. During winter, this process is reversed: warm groundwater is extracted to heat the building, while cold groundwater is injected back into the cold well.
The system typically operates with a cold well of 7–12 °C, suitable for direct cooling, and a warm well of 14–18 °C, which will be upgraded with a heat pump. The efficiency of ATES is particularly striking: direct cooling can reach a coefficient of performance (COP) of 30–40, ten times more efficient than conventional air-conditioning. Heating applications usually achieve a COP of 4–5.
In the Netherlands, ATES is predominantly applied in large-scale facilities with both heating and cooling demands, such as offices, hospitals, schools, shopping centers, data centers, and greenhouses.

EXPANDING THE APPLICATION OF ATES

Beyond conventional building applications, ATES is increasingly being used for large-scale thermal storage. Excess industrial heat, solar thermal energy, or surplus geothermal heat generated in summer can be stored in ATES for winter use. Storage temperatures range from approximately 60 °C for medium-temperature storage to around 90 °C for high-temperature storage. This form of large-scale heat storage contributes to balancing heat demand and supply in district heating networks. Moreover, ATES can play a role in addressing grid congestion by converting surplus electricity into storable heat, which can later be recovered.

KEY CHALLENGES

To understand how ATES can be scaled up across Europe, it is instructive to examine the Dutch experience and identify enabling factors and barriers.

Geohydrological Conditions and Knowledge
Successful ATES implementation requires suitable subsurface conditions, particularly aquifers in sand, limestone, or sandstone that allow both groundwater extraction and reinjection. The Dutch subsurface, largely composed of alternating sand and clay layers, is generally favourable. While geology cannot be altered, mapping and visualization tools based on hydrogeological data—such as ATES potential maps—are essential in reducing uncertainty and minimizing exploratory costs in new regions.

Legal and Regulatory Frameworks
Clear permitting processes are crucial. In many countries, groundwater extraction permits are obtainable, yet reinjection is not well-regulated. Establishing transparent frameworks and procedures for ATES licensing, supported by dedicated regulatory bodies, reduces uncertainties for developers and investors and facilitates broader deployment.

Financing and Business Models
Interestingly, ATES in the Netherlands has never relied on direct subsidies. Instead, public funding supported research, while challenges in well design, clogging, and environmental impacts were addressed collaboratively. The high energy efficiency of ATES historically allowed systems to achieve payback periods of 3 to 7 years. In recent years, policy priorities have shifted toward decarbonization and natural gas phase-out, leading to business models that are environmentally favourable but less economically attractive. In industrial contexts, implementation is slowed by complex energy demands and longer payback periods. Nevertheless, innovative business models, including the use of green investment funds with long-term horizons, offer promising opportunities for sustainable industrial applications.

The ATES Ecosystem
The Dutch success story cannot be attributed to a single factor. Rather, it has been shaped by entrepreneurship, perseverance, early adopters willing to implement systems in their buildings, and supportive public authorities. These combined efforts have resulted in thousands of systems and the emergence of specialized companies in design, engineering, supply of specific materials and implementation.
In many European countries, the innovation gap still needs to be bridged. International collaboration is therefore key to accelerating the learning curve by sharing knowledge, experience, and best practices. By working together, Europe can overcome barriers more quickly and contribute to a sustainable energy future.

REFERENCES

Dumas, P., (2025), EGEC Geothermal Market Report, EGEC 2025.

Fleuchaus, P., (2018), Worldwide application of aquifer thermal energy storage – A review, Renewable and Sustainable Energy Reviews 94, 861-876.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

- Renewable Heating and Cooling Solution for Low, Medum and High Temperature

INVESTIGATION OF DISTRICT HEATING AND COOLING SYSTEMS USING CARBON DIOXIDE AS HEAT TRANSFER MEDIUM

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SUMMARY

Key Words: Carbon Dioxide, CO2, District Heating, District Cooling
This article investigates the economic viability of CO_2 networks and their requirements for a stable energy supply. CO_2 networks are district heating and cooling systems that use carbon dioxide as a heat transfer medium instead of water. While these networks offer several advantages, they are also more complex. For instance, care must be taken to prevent condensation of the vapour line respectively evaporation in the liquid line. To address this issue, the article presents an approach involving a centrally controlled, decentralised buffer storage tank.
The economic analysis also yielded promising results. The best results were achieved with a combined heating and cooling supply using a lake as the energy source. When there is simultaneous demand for heating and cooling within the network, the CO_2 system can exploit all its strengths. However, promising use cases were also identified for its application as a pure cooling network.

INTRODUCTION AND SYSTEM DESCRIPTION

Climate change is leading to a steady increase in cooling demand in many parts of Europe. In Austria for example the number of days over 30°C has doubled to tripled in recent decades [GeoSphere Austria, 2022]. Installing efficient cooling systems is particularly challenging in inner-city areas characterised by existing buildings. A pipe-based combined heating and cooling supply using classic four-pipe systems is often not economically viable, resulting in many cases in the use of inefficient split air conditioning units. The CO_2 networks concept examined in this article could be a good alternative for supplying low-emission energy to consumers in dense urban areas. CO_2 networks are district heating and cooling networks in which carbon dioxide is used as a heat transfer medium instead of water. As shown in figure 1 on the left side, the basic network consists of a vapor and liquid line. Due to the low network temperatures of about 15°C free cooling can be provided for air conditioning by evaporating liquid taken from the liquid line and releasing it in the form of vapor to the vapor line. If lower temperatures are needed, decentralized heat pumps can be used to lower the temperatures further. In heating operation, vapor is taken out of the vapor line, condensed in a condenser-evaporator of the cold side of a heat pump and then released in the liquid line. Heating and cooling at the same time (at different consumer stations) is possible as well. This implies that the flow can go in both directions depending on the relative ratio between cooling and heating duties, and a central plant balances the loads. Another advantage of CO_2 networks is that uninsulated pipes with relatively small diameters can be used. The challenges lie in the complexity of the system and the high pressures (approx. 50 bar) in the pipes.
These kinds of networks are still at a very early stage of development. As part of the ongoing project CO2inloop, research was conducted into the economic viability of such CO_2 networks and the requirements for a stable energy supply.

METHOD

For the investigations described in this article, a small network comprising five consumers was modelled using Aspen HYSYS simulation software. The simulations were used to determine the dimensions of essential components, such as pipe diameters, and to identify a suitable control strategy that includes fail-safe measures to ensure a stable energy supply despite the network's increased complexity. A key focus was on implementing a system to prevent unintended condensation of the vapour line respectively evaporation in the liquid line. This can occur due to the energy input from the ground at times when no energy is consumed or heating and cooling demands cancel each other out in (parts of) the network. This issue could be resolved by adding a decentralized buffer storage tank, similar to an additional transfer station, which is centrally controlled to prevent standstills in the pipes. The storage tank can also be used for peak shaving, which partially offsets the additional investment.
To assess the system's economic viability, several use cases were defined, covering different applications, and the system was compared with conventional district heating and cooling networks. The distinction was made between a network dedicated to either heating or cooling, and a network providing both simultaneously. Additionally, the study examined which energy sources would be most suitable for a CO_2 network. The use of 'free' energy sources (river, lake,..) was compared with a connection to an existing conventional heating network.

RESULTS

The economic analysis yielded promising results. The best results were achieved with a combined heating and cooling supply. When there is simultaneous demand for heating and cooling within the network, the CO_2 system can exploit all its strengths. It has also been demonstrated that using a free energy source is advantageous and that it makes sense to combine the CO_2 network with a photovoltaic (PV) system. Figure 1 shows on the right side the results of this use case compared to a water-based low-temperature network (5G DEG) and a conventional heating and cooling supply with two separate networks (Conv. DEG). While Conv. DEG lags significantly behind, the CO_2 network and 5GDEG deliver similar results. Although the initial investment costs are higher for the CO_2 network, a higher net present value can be expected after 20 years.

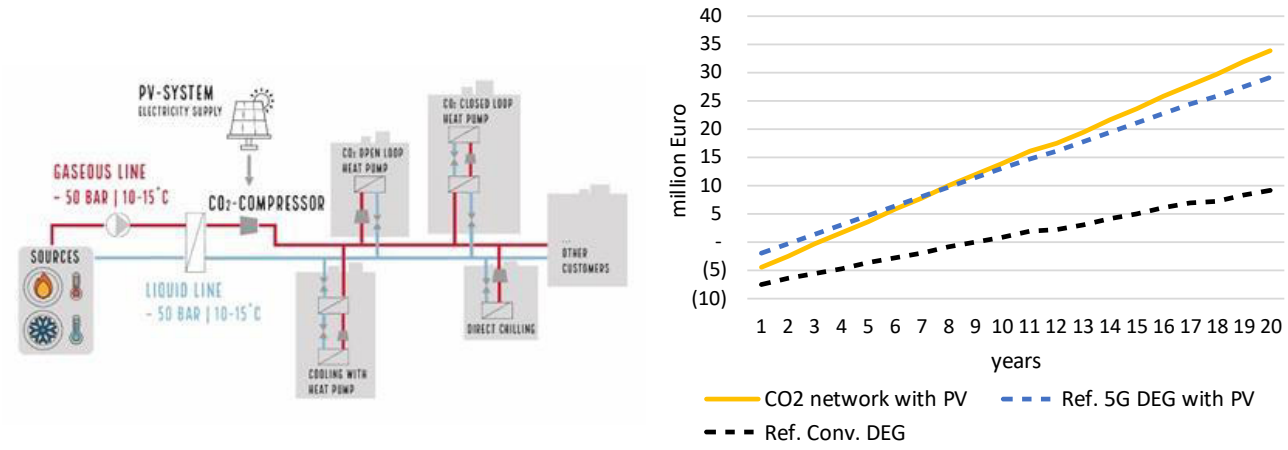


Fig. 1: Schematic system configuration of a CO2 network (left); Net present value curve of a CO2 network for use as a heating and cooling network compared with alternative pipe-based systems for heating and cooling supply (right)

Promising use cases were also found for its application as a pure cooling network, while using a CO_2 network purely for heating is not recommended.

REFERENCES

GeoSphere Austria: Massive Zunahme an Hitzetagen. online, 2022. LINK

CONFERENCE TOPIC

Future District Heating and Cooling Solutions

A SPATIAL MULTI-CRITERIA ANALYSIS FOR OPTIMAL HEAT PUMP PLACEMENT IN MUNICIPAL HEAT PLANNING

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SUMMARY

Decarbonizing the heating sector requires solutions for areas with decentralised supply. Planning future proof heat supply in these areas is a challenge for many municipalities in Germany. Using geospatial data to plan preliminary space potentials and uncover restrictions will facilitate area-assessment. This will help in direct communication with residents and offers potential for considered neighbourhoods.
Using the city of Aachen as a case study, this paper analyses the optimal placement of heat pumps based on geospatial criteria and noise emissions. A platform-based approach provides flexible access to necessary building data in selected areas. Future developments include implementing financial incentives and further technologies.
Key words: municipal heat plan, spatial analysis, design optimization, noise immissions

INTRODUCTION

The necessity of the global energy transition requires a decarbonization of the heating sector, which currently accounts for approximately 83 % of CO_2 emissions in German housing (DESTATIS, 2023). In Germany, the federal mandate for a municipal heat plan provides the strategic framework for this transition at the local level. These plans identify target areas for district heating networks and decentralized solutions. (Bundestag, 2023)
While air-sourced heat pumps (ASHP) are considered essential for decarbonization (BWP e.V., 2025), a lack of organisational capacity hinders municipalities from planning and regulating their implementation in decentralised supply areas, creating a gap between strategic goals and practical application (Riechel and Walter, 2022).
Another obstacle to the large-scale installation of ASHPs is exceeding noise protection limits for neighbouring buildings, so-called noise immissions (Sangsinsorn and Nienborg, 2025). This is especially relevant in densely populated areas (MUNV NRW, 2025), making the city of Aachen an ideal case study to develop solutions.
This work develops a scalable, transferable, spatial optimization model that identifies the most suitable locations for ASHP by integrating the results of Aachen's municipal heat plan with a multi-criteria analysis. By considering factors such as building-specific heat demand and geometries combined with noise immission limits, this work creates a holistic view of heat transformation planning for real neighbourhoods.

METHODOLOGY

Not many studies focus on the relation and information gain of using real data for actual planning purposes in municipalities. In terms of retrofitting, most studies are done at building level and spatial uncertainty and energy systems are seldom considered together. (Ali *et al.*, 2020; Guo *et al.*, 2023).
This research takes a first step to collect building information in a digital twin on a data-platform and reuse it to aid the heat transformation in cities on a district scale. Using local data to model the neighbourhoods as well as their demands allows to include regional information which is often missed when looking at building archetypes (Halloran *et al.*, 2024).

The developed data-platform stores all available data in a data model based on concepts such as FIWARE smart cities data models or schema.org. This structure forms the basis for various modular frameworks.
One modular framework is the developed multi-criteria analysis. It is based on work previously done by (Reichl, 2021; Greif, 2023) and expands it by adding the ability to examine any neighbourhood using detailed geospatial data available from the heat plan as well as public data sources in a data platform. Using this data, this study models and evaluates how ASHP placement impacts the feasibility of a complete, decentralized supply in a real neighbourhood. At this stage, no existing ASHP or retrofitting costs are considered.
The placement of each ASHP is individually optimized to comply with German noise regulations (TA Lärm, 2017) by minimizing immission at neighbouring buildings, while also seeking to reduce distances to the owner's building and adjacent streets. This optimization occurs within a valid area around the building and accounts for physical sound barriers and soil properties influencing noise propagation.
In multiple iterations these points are put into context to account for noise interferences of multiple ASHP. The placement will be calculated repeatedly until an optimum is reached. If a building cannot install a ASHP due to noise immission, the benefit of a casing will be considered and shown in the result.

USE CASE AND RESULTS

The methodology is evaluated by analysing three neighbourhoods of differing structure situated in decentralised heat supply areas in Aachen. While existing literature highlights placement challenges primarily in densely built-up areas (Sangsinsorn and Nienborg, 2025), his study analyses different settlement typologies to provide a comparative assessment to validate this assumption and highlight how structural density impacts feasibility.
Results (see Fig. 33) for an area with mainly terraced houses show optimal ASHP placement with necessary distance to noise immission points at the protection area of surrounding buildings is in all cases possible.
These results are similarly obtainable for any neighbourhood in the city, as the necessary data is readily available in the data-platform.



FIG. 33: OPTIMAL ASHP POSITIONS IN A NEIGHBOURHOOD (MOSTLY TERRACED HOUSES)

CONCLUSION

Transferable and scalable systems allow to research local spatial recommendations for cities. The current research platform already enables the assessment of different areas in the city on a detailed information level.
The performed study allows to locally research potentials for ASHP and possible restrictions. To address current limitations and enhance the information gain for municipalities, more heating systems might be added to assess their influence on the noise pollution. Furthermore, supply concepts between central and decentral will be evaluated, as (Reichl, 2021) already discussed their benefit for reducing noise pollution.

Generally, this approach allows deciders to simply and quickly assess potentials in - neighbourhoods based on realistic building model assumptions and placements. This work and future improvements addresses needs in the planning and decision making of municipalities in the future.

REFERENCES

Ali, U. *et al.* (2020) 'A data-driven approach to optimize urban scale energy retrofit decisions for residential buildings', *Applied Energy*, 267, p. 114861. Available at: https://doi.org/10.1016/j.apenergy.2020.114861.

Bundestag (2023) *Gesetz für die Wärmeplanung und zur Dekarbonisierung der Wärmenetze*, *WPG*.

BWP e.V. (2025) *Wärmepumpen: Markt geht auf 193.000 Geräte zurück, aber Vertrauen in die Förderung steigt*, *Bundesverband Wärmepumpe e.V.* Available at: https://www.waermepumpe.de/presse/pressemitteilungen/details/waermepumpen-markt-geht-auf-193000-geraete-zurueck-aber-vertrauen-in-die-foerderung-steigt/ (Accessed: 28 July 2025).

DESTATIS (2023) *Umweltökonomische Gesamtrechnungen (UGR) Private Haushalte und Umwelt*. Statistischer Bericht 5851319217005. Wiesbaden: Statistisches Bundesamt (Destatis).

Greif, S. (2023) *Räumlich hoch aufgelöste Analyse des technischen Potenzials von Wärmepumpen zur dezentralen Wärmeversorgung der Wohngebäude in Deutschland*. Dissertation. Technische Universität München.

Guo, T. *et al.* (2023) 'A novel approach to address spatial uncertainties and simultaneously optimize concept, scope, and equipment design in district heating system', in. *2023 Building Simulation Conference*. Available at: https://doi.org/10.26868/25222708.2023.1187.

Halloran, C. *et al.* (2024) 'Data-based, high spatiotemporal resolution heat pump demand for power system planning', *Applied Energy*, 355, p. 122331. Available at: https://doi.org/10.1016/j.apenergy.2023.122331.

MUNV NRW (2025) *Umgebungslärm in NRW*, *Ministerium für Umwelt, Naturschutz und Verkehr des Landes Nordrhein-Westfalen*. Available at: https://www.umgebungslaerm.nrw.de/umgebungslaerm (Accessed: 28 July 2025).

Reichl, C. (2021) *5: Report on heat pump installation with special focus on acoustic impact*. IEA Heat Pumping Technologies.

Riechel, R. and Walter, J. (2022) 'Kurzgutachten Kommunale Wärmeplanung'. Edited by Umweltbundesamt.

Sangsinsorn, S. and Nienborg, B. (2025) 'Noise immissions by air source heat pumps: A case study in Germany', *Building and Environment*, 279, p. 113037. Available at: https://doi.org/10.1016/j.buildenv.2025.113037.

TA Lärm (2017) 'Technische Anleitung zum Schutz gegen Lärm'. Berlin. Available at: https://www.verwaltungsvorschriften-im-internet.de/bsvwvbund_26081998_IG19980826.htm.

CONFERENCE TOPIC

- 1.16. Transform Cities: Holistic Approaches to Sustainable Urban Energy
- 2.08. Spatial Energy Planning with Emphasis on Renewable Energies

UNDERSTANDING THE HYGROTHERMAL BEHAVIOUR OF THE COVER OF LARGE-SCALE THERMAL ENERGY STORAGE SYSTEMS FOR PERFORMANCE-ORIENTED DESIGN

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SUMMARY

The hygrothermal behaviour of the cover of large-scale thermal energy storage (LTES) systems has a significant impact on their performance and costs. The presence of moisture within the insulation material from the construction and from penetration through polymeric liner results in increased thermal losses and material degradation. A LTES cover design that considers the insulation material properties and the complex heat and moisture transfer phenomena in presence of high temperature gradients is necessary. Scope of the work is the definition of specific guidelines about material selection and cover design to ensure its optimal operation.
Keywords: large scale thermal energy storage; thermal insulation; convection; heat and moisture transfer; design

INTRODUCTION

The increased number of large thermal energy storage (LTES) systems in Europe supports the integration of renewable energy in district heating grids and the broader energy transition. To ensure long-term, cost-effective operation, reliable designs are essential. The buried pit thermal energy storage (PTES) solution common in Denmark can be considered the state-of-the-art for sensible LTES, with successful examples like the PTESs in Dronninglund and Høje-Taastrup. The most critical component is the insulated lid, which should limit thermal losses. In floating cover solutions (typical in "Danish-type" LTES) the cover consists of a lightweight insulating structure, enclosed between an impermeable liner in contact with the high temperature LTES water and a diffusion-open barrier for moisture control (Sørensen et al. 2024). Moisture penetration due to diffusion and leakages is responsible for a rapid degradation of the insulation material and an increase of the local thermal losses linked to the latent heat of the water (see Figure 1). Frequent maintenance and replacement of the LTES lid require not only the purchase of new construction material, but also interruption of the storage operation.

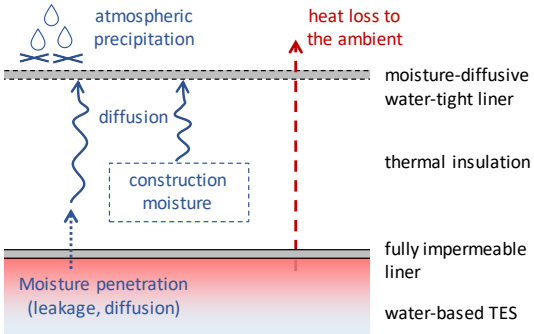


Fig. 1: Sketch of a LTES insulated cover and the involved heat and moisture transfer processes.

A further issue in LTES lids with porous bulk insulation is the increased heat transfer from natural convection. Thermal images of PTES systems in Gram and Vojens reveal brain-like patterns, indicating convective cells that enhance local heat loss (Sifnaios et al. 2021). In these systems, the insulation material used was LECA, but convection remains a concern with also other porous materials due to strong upward heat fluxes from high temperature gradients. Detailed studies to investigate this aspect have been conducted by (Drück et al. 2022),

who considered FGG and mixture of FGG and expanded perlite (EP). Further studies on FGG with different compaction rates showed that the presence of convection even with compaction contributes in a faster removal of the trapped moisture, but results in poor insulation performance (Tosatto et al. 2023).
This work aims to analyse heat and moisture transfer in LTES lids to identify their dependence on the material properties and the specific operating conditions. The goal is to define specific guidelines concerning the selection of insulation materials and the lid design to prevent degradation phenomena related to moisture and convection.

METHODS

As introduced in the previous paragraphs, the issues with LTES cover insulation performance are related to the material degradation linked to the development of natural convection and moisture presence.
Convection is not an issue in materials like XPS or Nomalen, but these materials present a very high moisture transfer resistance which makes the moisture removal more challenging. The convection risk is instead not negligible in materials like bulk porous insulation, although the removal of moisture is easier.
An initial analytical assessment of convection risk is performed using the Rayleigh number. Material tests using mock-ups to assess the drying behavior of the materials are used as support for the implementation of numerical models. The mock-up consists of a (1x1x0.5) m open steel case filled with the test material. To replicate the operation conditions of a LTES cover, a heating plate is placed beneath the case to maintain a constant set point temperature, as described by (Tosatto et al. 2023). Insulation materials suitable for the application in LTES covers and investigated in this study are FGG, EP, expanded glass granules (EGG) and a mix of EGG and FGG.

RESULTS

Figure 2 presents the Rayleigh number and the drying curves for the investigated materials. Materials with larger grains like the FGG are prone to the development of convection, with higher risk increasing the temperature difference across the material. The limit of $Ra=4\pi^2$ generally defines the threshold for the convective heat flow development. The normalized drying curves from the experimental tests show that the presence of convection supports the drying of the material, but at cost of the insulation performance.

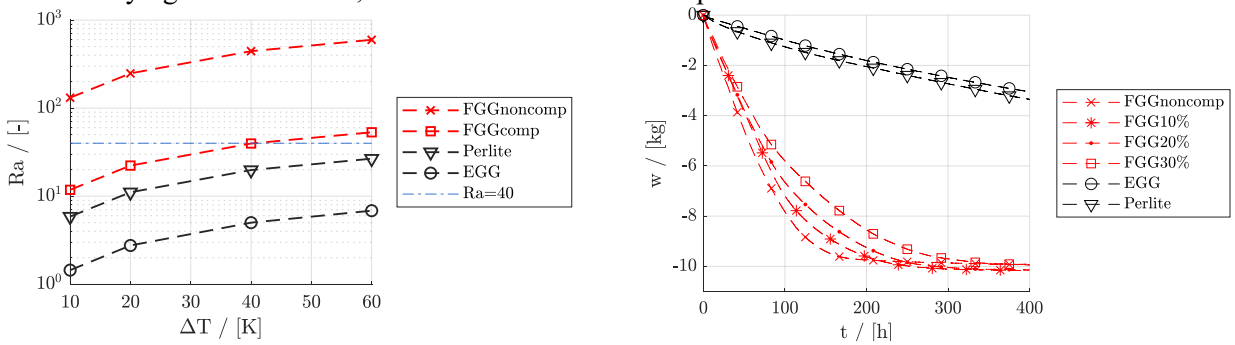


Figure 2: (a) Rayleigh number with upward heat transfer for different temperature differences. (b) Normalized drying curves of the investigated bulk insulation materials from the cover mock-up drying test (with ΔT=40 K).

REFERENCES

Sørensen, P. A., et al. (2024). Design, implementation, and monitoring results from the 70 000 m^3 pit thermal energy storage (PTES) in Høje Taastrup, Copenhagen. *Proceedings of the 16th IEA ES TCP International Conference on Energy Storage (ENERSTOCK 2024)*. https://doi.org/https://doi.org/10.5281/zenodo.13784976

Sifnaios, I., et al. (2021). Thermal inspection of water pit heat storages using drones. *Proceedings - ISES Solar World Congress 2021*, 925–931. https://doi.org/10.18086/swc.2021.35.02

Drück, H., et al. (2022). Erweiterung und Optimierung der solaren Nahwärmeversorgung Hirtenwiesen II in Crailsheim sowie Begleitforschung zu solarer Nahwärme und saisonaler Wärmespeicherung *(CROW)*. 1–130.

Tosatto, A., et al. (2023). Influence of Heat and Mass Transfer on the Performance of Large-Scale Thermal Energy Storage Systems. *Proceedings of the IRES Conference 2022*, 470–488. https://doi.org/10.2991/978-94-6463-156-2_30

CONFERENCE TOPIC

Emerging Heat and Cold Storage

ENERGY FROM WASTEWATER: SUCCESSFUL IMPLEMENTATIONS, FURTHER POTENTIAL AND FUTURE OUTLOOK

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SUMMARY

Since 2018, the EU recognizes energy from wastewater as a renewable energy source, offering significant potential for decarbonizing heating and cooling. In this paper, recent projects in Austria (Tulln, Linz and Vienna) are presented, which show successful applications in public, industrial, and residential settings. These projects highlight wastewater's flexibility for both heating and cooling. Further, this paper talks about the future potential for energy from wastewater, including retrofitting buildings, inhouse systems and the use of the treatment plant effluent for district heating. Despite progress, implementations on a broad scale are still missing. To address this issue, the authors talk about the necessary policymaking to increase the use of this energy source and support the transition towards a renewable heating and cooling supply.
Keywords: Energy from wastewater, decarbonization, building sector, industry, heating and cooling.

INTRODUCTION

Since 2018, the EU recognizes energy from wastewater as a renewable energy source and thereby its valuable contribution to the achievement of the climate goals (Directive (EU) 2018/2001). Space and water heating require about 75% of the energy consumption, which today is mostly covered by non-renewables (REN21, 2023).
Energy from wastewater is available all year round and can be tapped with a combination of modern heat exchangers and heat pumps. These advantages are slowly being recognized – also in Austria – by energy suppliers as well as by those responsible for wastewater management and the number of implementations is rising every year. The experiences from these reference projects show that the technology for using wastewater heat und cooling is running well and supplies the promised heating/cooling demand. Additionally, the references show the broad application of energy from wastewater: from in-house solutions for residential buildings, the supply of community buildings from the public sewer to the use of industrial wastewater for a contribution towards a energy-neutral industry.

RECENT IMPLEMENTATIONS IN AUSTRIA

In the last two years, several projects have been implemented in Austria. We want to present three of these projects, all based on the experiences from previous implementations and research projects such as Thermaflex and Wien Blumental. The three projects demonstrate the versatile use of wastewater for heating and cooling:

I) **Town hall Tulln (2024):** The sewer next to the town hall is used to replace a gas boiler for heating the building. The heat exchangers were installed in the sewer over a length of 88 m, a subsequent heat pump provides the necessary temperature. In total, the building is supplied with up to 100 kW of heat. Since the implementation in 2024, the system is running successfully and as expected.

II) **Voest Alpine Automotive Linz (2024):** A cooling channel is used for heating of the production hall and office building. Using energy from wastewater supports transitioning this industrial site from gas-based to renewable heating. The cooling channel was equipped with a total of 160 m of heat

exchangers. Two heat pumps provide a total of 1 MW heating, running smoothly since the implementation in 2024.

III) **Inhouse implementation Vienna (2025):** A large-scale inhouse project is currently planned and the implementation will start by the time of the ISEC conference. This project uses domestic wastewater from the building to supplement the heating. It will be the first project of this size in Austria using the building's own wastewater and the Drain2Energy® inhouse heat exchanger and separator. By the time of the conference, we will be able to share more insights into this project.

For the conference full paper and presentation, we will be giving further details on these implementations including technical details, monitoring data, photos and more.

POTENTIAL OF ENERGY FROM WASTEWATER

The potential of wastewater for the decarbonization of the heating and cooling sector is slowly being recognized. Based on our experience in this field, we want to point out specific areas, where we see great potential and increasing demand:

I) **Existing buildings in urban areas:** Retrofitting existing buildings in dense urban areas with renewable heating and/or cooling is a huge challenge. Where other renewable energy sources are often lacking, wastewater from the public sewer or the buildings' own wastewater can play a key role in urban decarbonization.

II) **Inhouse:** Using the building's own wastewater to support the supply with renewable heating and cooling in case no public sewer is in near distance – this can be especially interesting for residential buildings, hospitals, food processing industry, retirement home and many more possible applications.

III) **Treatment plant effluent:** The effluent from treatment plants holds a constantly high potential for heating. The effluent is particularly well-suited for feeding into district heating networks, for example as a year-round base supply or as a summer supply to reduce the amount of biomass or gas needed.

IV) **Cooling:** With increasing summer temperatures, cooling is already and will become a more urgent topic in the future. Wastewater can not only be used for heating but also for cooling – an advantage offered by very few energy sources.

V) **Digitalization of the wastewater sector:** Monitoring data from energy from sewer and wastewater plants can contribute to the digitalization of the sector, aligning with the goals of Wastewater Management 4.0.

FUTURE OUTLOOK

Although the thermal potential of wastewater is increasingly recognized, a large-scale roll-out is still lacking. To fully realize this potential targeted policymaking is needed. This includes integrating energy from wastewater into energy spatial planning on a nation-wide level, simplifying access to information for energy planners, building owners, communities, etc. Further, supportive funding schemes for first evaluations and potential assessments as well as subsequent pilot and demonstration projects are needed.

Strengthening the interface between the (waste) water and energy sectors remains crucial to unlocking synergies and accelerating the transition toward a resilient and climate-neutral infrastructure.

REFERENCES

Directive (EU) 2018/2001. Promotion of the use of energy from renewable sources (recast). European Parliament and of the Council. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018L2001

REN21, (2020), Renewables 2020 Global Status Report. Paris, France: REN21 Secretariat.

CONFERENCE TOPIC

Excess Heat and Resource Recovery from Low-grade Sources

EXAMINING A SALT-BASED ENERGY STORAGE SYSTEM WITH AN EMPHASIS ON LATENT HEAT

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SUMMARY

Molten salt energy storage systems are increasingly attractive, but so far, only the sensible heat has been utilized. Some latent heat can be harnessed even in current setups without damaging the system's structure. Salt crystallization was experimentally tested on a semi-industrial rig with a vertical shell-and-tube heat exchanger in a salt tank. Using this data, a CFD model was created, validated with measurements, and is suitable for scaling. Thanks to CFD simulations and detailed spatial and temporal data, we can accurately determine where and when salt crystallizes. Measurements of temperature and heat flow over time, under various boundary and initial conditions, included all major operating scenarios for larger systems. Complete crystallization of the salt could boost thermal energy output by approximately 10%. However, in practice, crystallizing around 60% of the salt is more effective, as solid salt on heating surfaces severely restricts heat flux during reheating, thereby reducing load cycling flexibility.

INTRODUCTION

Renewable energy sources, such as wind and solar, are unpredictable and can challenge grid stability. Converting electricity at low cost into heat, or reversing this during peak demand, is a promising solution. Molten salt storage offers an alternative to traditional energy sources, providing improved efficiency and stability for industrial energy management. Phase change materials (PCMs) are increasingly recognized for their ability to store thermal energy by absorbing or releasing large amounts of latent heat during phase transitions. Notably, PCMs can maintain near-constant temperatures during these transitions, which enhances system performance and efficiency, especially in renewable energy applications. Although the current focus has been on the sensible heat of salt, utilizing the latent heat could significantly boost energy output. Therefore, a semi-industrial test rig was developed to study the phase change of salt, capable of melting salt using both compressed air and electric heating. Heat losses were measured through stationary tests. Temperature and heat fluxes were measured over time under various boundary and initial conditions to reflect all relevant operating states. From this data, a precise energy balance was calculated. The potential to crystallize the salt, maximizing the use of its latent heat, is under investigation. Based on these experiments, a 3D CFD model was created to gain a better understanding of the crystallization process.

RESULTS

This study describes a thermal energy storage system that uses solar salt as the heat storage medium and compressed air as the heat transfer fluid. The system is built as a vertical U-pipe shell-and-tube heat exchanger. The key component of this setup is the salt tank, as shown in Figure 1. The construction features the main zones: salt (blue), metal (orange), compressed air (green), a gas space above the salt (turquoise), the heating element (black), and a separating layer between the salt and gas regions (red). The air inlet is located at the bottom left, while the outlet is at the bottom right corner, marked by green arrows. The temperature distribution of the salt at the end of thermal loading with the heating element serves as the initial condition for the transient thermal

discharging simulations and experiments. During thermal loading experiments, only the heating element was turned on. The initial salt temperature at the beginning of the transient simulations and experiments was 550°C.

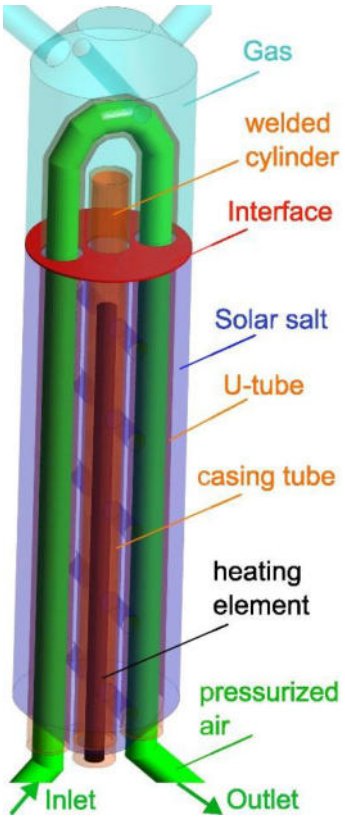


FIGURE 35 – SALT TANK

The transient testing of the salt storage tank involved four main stages. Initially, an internal heating element was used to thermally load the tank, raising the temperature of the salt. When the salt reached an average temperature of 550°C, heating was stopped, and pressurized air was introduced into the system. This marked the start of the thermal discharge phase, where thermal energy was extracted through the flow of compressed air. The test ended when the salt fully solidified, indicated by an average salt temperature below 220°C; the salt's temperature at the end of the experiment ranged from 97°C to 200°C. The heat flow during thermal discharge is presented in Figure 34. The air inlet temperature for all experiments in Figure 34 was 85°C, with curves arranged in ascending order based on air mass flow. Higher mass flow rates lead to notably higher heat flow peaks. For example, at a maximum air flow of 1260 W (0.0091 kg/s), the peak heat flow is nearly twice as high as at the minimum air flow of 680 W (0.0052 kg/s). Consequently, the extraction time is shorter due to the lower inlet temperature and higher air flow rates. The maximum heat flow density, indicated by the pink line at about 5 minutes, reaches approximately 35000 W/m². The thermal energy quantity of the storage tank when it is completely discharged and the latent heat is used is more than 3000 kJ. However, some of this heat is available at a very low temperature level. At an average salt temperature of 200°C, a temperature difference of approximately $\Delta T = 100°C$ can be achieved between the salt and the air. On an industrial scale, it is not valuable to have fluid temperatures at a lower level. Therefore, the amount of energy in the storage tank up to this salt temperature is of interest. The thermal energy in the storage tank amounts to approximately 2600 kJ when the average salt temperature ranges from 550°C to 200°C. The maximum increase in thermal energy output resulting from the use of the latent heat of the salt is 10%.

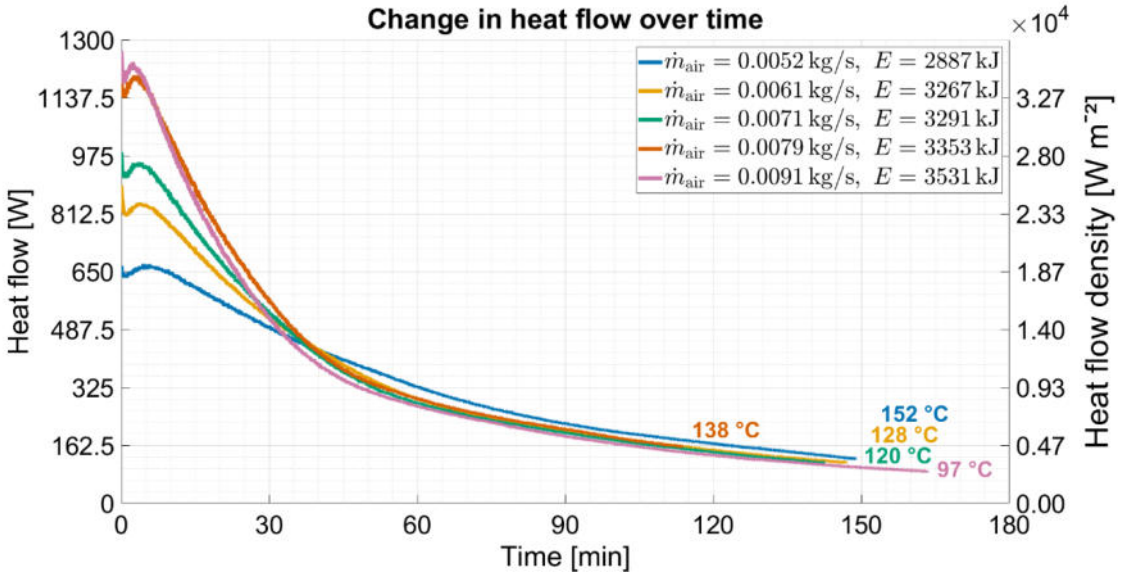
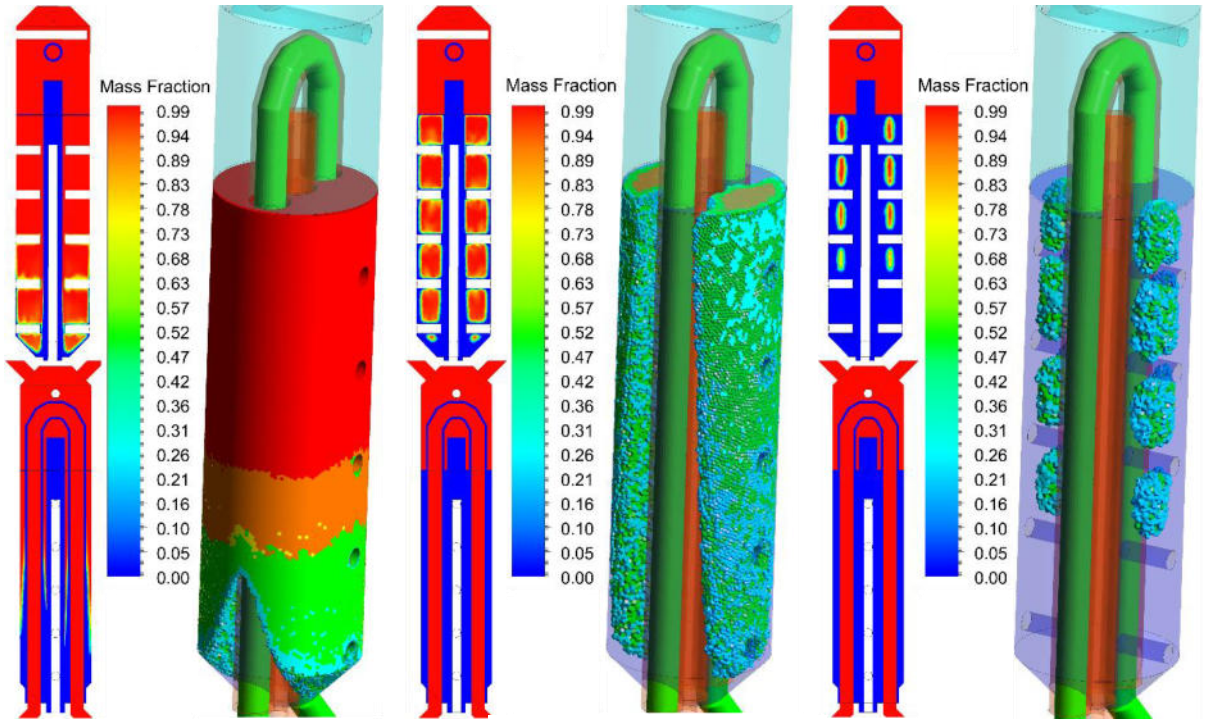


FIGURE 34 - THERMAL DISCHARGE PROCESS WITH VARIABLE AIR MASS FLOW AND CONSTANT INLET AIR TEMPERATURE OF 85°C

The phase state of the salt is indicated in binary form for each cell, using the mass fraction parameter, where 1 denotes liquid and 0 means solid. In Figure 36, the elements within the salt domain are colored based on their phase: red for liquid, and orange, yellow, green, and turquoise for phase-change-state. Crystallization initiates first around the air pipes, as shown in Figure 36(a), because this area experiences the highest temperature gradient.

The solid salt front expands from bottom to top around the air tubes, with the salt displaying axial temperature stratification—colder at the bottom and warmer at the top—due to natural convection of rising warm liquid salt. Once the salt near the air pipes is fully crystallized, the crystallization front moves toward the heating element, as depicted in Figure 3(b). Continued thermal discharge causes the solid salt to grow upward along the heating element's casing. At this stage, the outer surface of the heating element is wholly covered with solid salt, leaving only the remaining liquid pockets, which also undergo phase change from bottom to top over time. By the end of the thermal discharge, nearly the entire salt domain is solid, as shown in Figure 3(c). The remaining liquid or transitional salt phase constitutes a low single-digit percentage of the total salt domain at the end of the experiment. Starting operation with Solar Salt at 550°C enables the salt tank to be thermally discharged for about two to three hours, reaching roughly 60% salt crystallization around 150 minutes after start, as shown in Figure 3(b). Once this point is reached, it is advisable to begin the next thermal loading cycle. This approach increases the total usable thermal energy by approximately 6%, thanks to the added latent heat. Operated in this manner, a significant portion of the latent heat of the salt can be used, without compromising the system's structural integrity.



(a) 121MIN AFTER START (b) 156MIN AFTER START (c) 217MIN AFTER START

FIGURE 36 – MASS FRACTION ON RELEVANT TIME STEPS DURING CRYSTALLIZATION (THERMAL DISCHARGE) PROCESS

CONFERENCE TOPIC

1. Flexibility and Stability in Thermal and Electric Grids
2. Next-Generation Technologies for Renewable Energy and Resource Efficiency
3. Circular Economy Strategies for the Energy Transition
4. Renewable Heating and Cooling Solutions for Low, Medium, and High Temperature ApplicationsEmerging Heat and Cold Storage
5. Coupling of Energy Sectors

THE POTENTIAL OF AGRI-SOLAR THERMAL SYSTEMS FOR DUAL LAND USE COMBINING AGRICULTURE AND LARGE-SCALE SOLAR HEAT GENERATION

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SUMMARY

In view of the restricted availability of land for large-scale solar thermal systems in district heating, the creation of synergies in combining agricultural and energetic land use is of particular interest. Hence, the paper provides an evaluation of the conceptual options for Agri-Solar Thermal Systems. In addition, it outlines the requirements, boundary conditions and further development needs for these systems. The investigation reveals that vertical Agri- Solar Thermal with insulating glass collectors is a promising concept due to the collectors' bifaciality and low adaptation costs. Consequently, its energetic potential is analysed in more detail. Applying an analytical modelling approach, it was found that a vertical bifacial Agri- Solar Thermal system is capable to deliver a similar specific solar yield to that of a conventional ground-mounted system, while reducing land use for collector mounting to one third. Finally, testing of bifacial collectors in a laboratory setting is highlighted and steps towards the development of a pilot site are described.

EVALUATION OF CONCEPTUAL OPTIONS FOR AGRI-SOLAR THERMAL SYSTEMS

Solar thermal (ST) energy in district heating offers vast potential for climate-neutral heat supply. A key challenge for large-scale ST plants is land availability in densely populated areas, as greenfield, ground-mounted ST is dependent on proximity to settlements to minimise transport losses. Agri-Solar Thermal (Agri-ST) concepts provide solutions for the dual utilisation of agricultural land for both farming and heat generation. They therefore promise an innovative answer to the competition for land. Following the system categorisation of Agri-Photovoltaics (Agri-PV), the potential Agri-ST concepts can be characterised as overhead and vertical systems (fig. 1). In a conceptual analysis, qualitative requirements and boundary conditions for Agri-ST were defined considering well developed and standardised requirements for Agri-PV systems. The latter were transferred to ST applications and supplemented by specific aspects of conventional ground-mounted ST systems. The results of the study show that requirements of Agri-PV systems can be transferred to Agri-ST. Exclusion criteria against a technically and economically feasible realisation have not been found.



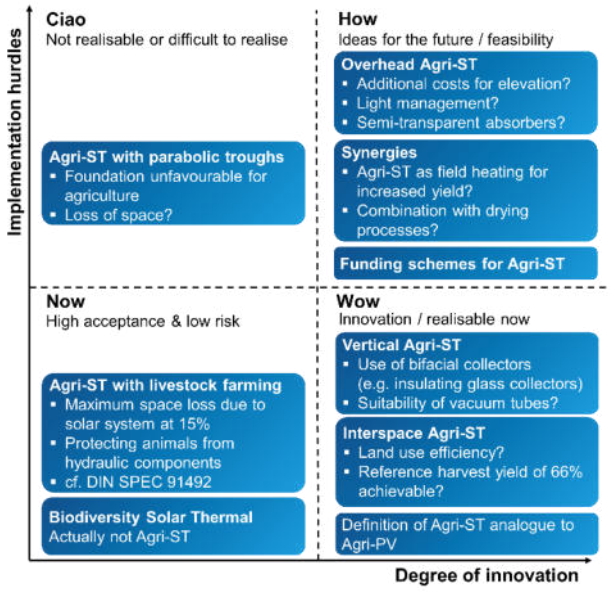


Fig. 1: Overhead (top) and vertical Agri-PV (bottom; with bifacial modules in east/west orientation)

Fig. 2: Qualitative characterisation and evaluation of Agri-ST concepts

A qualitative evaluation of Agri-ST concepts was performed based on this (fig. 2), where specifically vertical Agri-ST with insulating glass flat-plate collectors appears to be a promising concept due to the collectors' bifaciality and low adaptation costs.

THE POTENTIAL OF VERTICAL AGRI-ST WITH BIFACIAL FLAT-PLATE COLLECTORS

Following the conceptual analysis, the potential of vertical Agri-ST with bifacial flat-plate collectors has been further analysed. In this novel approach, insulating glass flat-plate collectors are installed vertically facing east/west with a row spacing of 10-15 m which enables agricultural use in between (fig. 3). A key novelty lies in the bifacial design of the insulating glass flat-plate collectors, which feature glass covers and highly selective absorber coating on both sides and thus allow for vertical orientation (fig. 4). The vertical alignment reduces shading on crops, enhances light distribution, and optimises heat generation throughout the day.

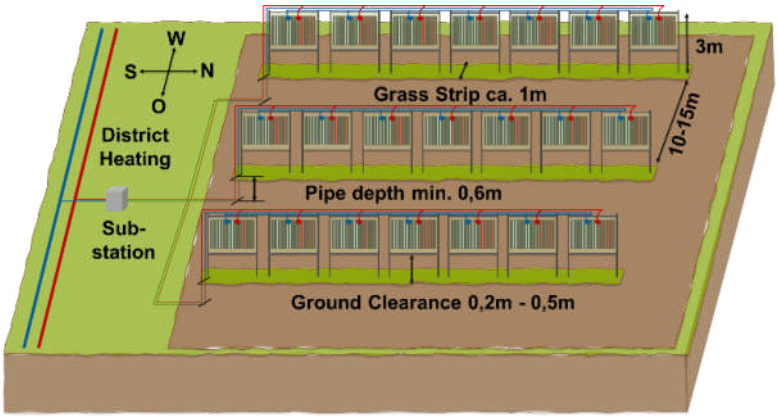


Fig. 3: Pilot site layout for vertical Agri-ST with bifacial collectors



Fig. 4: Bifacial collector in lab testing

Aiming at the analysis of the energetic potential of a bifacial solar thermal system, a theoretical study was performed to obtain the specific thermal energy yield for a reference year. An analytical modelling approach based on solar irradiation analysis was chosen for this purpose. It was shown that the annual specific collector yield of a vertical bifacial collector (90° inclination angle; east/west oriented) was at 451 kWh/m² for Kassel (DE). This is 0.9% less than a conventional collector facing south at 45° inclination but with increased seasonality (fig. 5). Although the methodology applied contains several assumptions and restrictions, the results indicate that bifacial Agri-ST is capable to deliver a comparable amount of thermal energy per collector while reducing land use for the system to one third. Following the analysis of the potential, lab testing with bifacial collectors is performed and a pilot site is developed (cf. fig. 3 and 4).

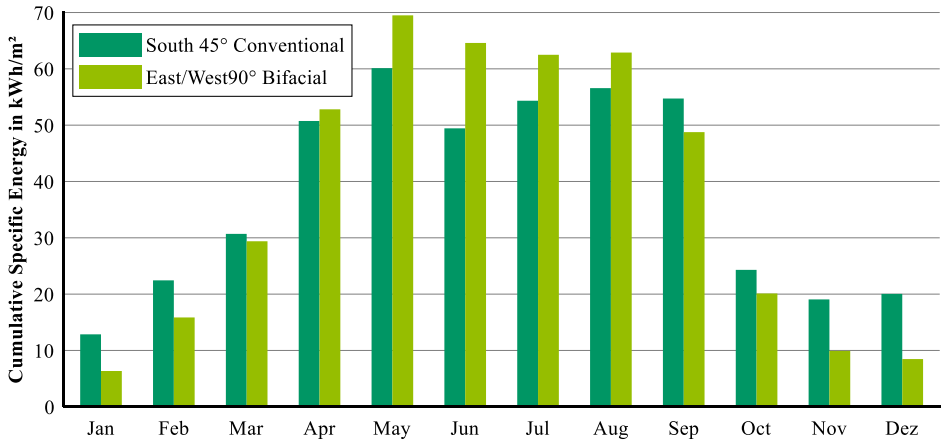


Fig. 5: Monthly specific solar yield for conventional and vertical oriented collectors (location: Kassel, DE)

CONFERENCE TOPIC

Conference topic this abstract refers to: *Future District Heating and Cooling Solutions*

RETROFITTING EXISTING BUILDINGS IN AUSTRIA: CURRENT STATUS AND FUTURE TRAJECTORIES

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SUMMARY

This paper reviews Austria's existing building renovation and retrofit status, technical systems, and trends, linking them to China's needs to explore Austria's experiential value. The study shows Austria has excelled in deep energy-saving and low-carbon transition via technical integration, "regulatory mandates plus market incentives" policies, and social coordination-offering China valuable references. Austria's practices in clean heating, whole-life-cycle carbon accounting, and community participation provide insights for China to tackle fragmented technologies, weak policy implementation, and low public engagement. Future China-Austria cooperation in technology localization and policy innovation will boost global construction decarbonization.

Keywords: Existing building retrofit, Low-carbon transition, Austria experience, Construction decarbonization

INTRODUCTION

Improving the energy performance of buildings is a critical strategy for climate change mitigation. The carbon emissions from the building sector are responsible for 37% of the global energy-related CO_2 emissions (in 2021, the total energy-related CO_2 emissions amounted to 36.6 Gt) (see Fig. 1(a)[1]). [1]. Decarbonizing existing multi-stogey residential buildings-through retrofitting and upgrading-is therefore vital. This review focuses on two contexts with ambitious climate goals：China aims to achieve carbon neutrality by 2060, whereas Austria has set a target of reaching climate neutrality by 2040 (see Fig. 1(b)[2]). Compared to Austria-where there is a 50-year interval between hitting the carbon peak and attaining carbon neutrality-China faces an exceptionally tight timeline and arduous tasks. For China, the span between its carbon peak and the goal of carbon neutrality is only 30 years. This underscores the urgency for China to learn from Austria's advanced experience in building retrofit-particularly its technological pathways and practical models for decarbonizing existing buildings. This paper synthesizes key academic findings on building renovation decarbonization across technology, decision-making, policies, carbon accounting, economics, and market factors, highlighting common themes and contextual differences.

Multiple studies underscore the potential impact of retrofitting. For instance, World Energy Outlook Special Report [3] reveals energy-efficient renovations can significantly reduce residential energy use and associated CO_2 emissions. Notably, their analysis revealed that low-income households and families with children benefit the most from such retrofits (due to disproportionately high prior energy burdens). This suggests retrofitting not only aids climate goals but also has equity co-benefits. Similar findings are echoed in European contexts [4,5]: the EU's Renovation Wave initiative emphasizes that upgrading homes improves living conditions and reduces energy poverty (over 9% of EU citizens struggled to heat their homes in 2022). Both China and the EU thus recognize building retrofits as a cornerstone of their carbon reduction policies. However, the scale of the

challenge is immense-about 75% of the EU's building stock is energy-inefficient, with current renovation rates around only 1% per year, and China likewise has a vast inventory of aging buildings with high retrofit potential.

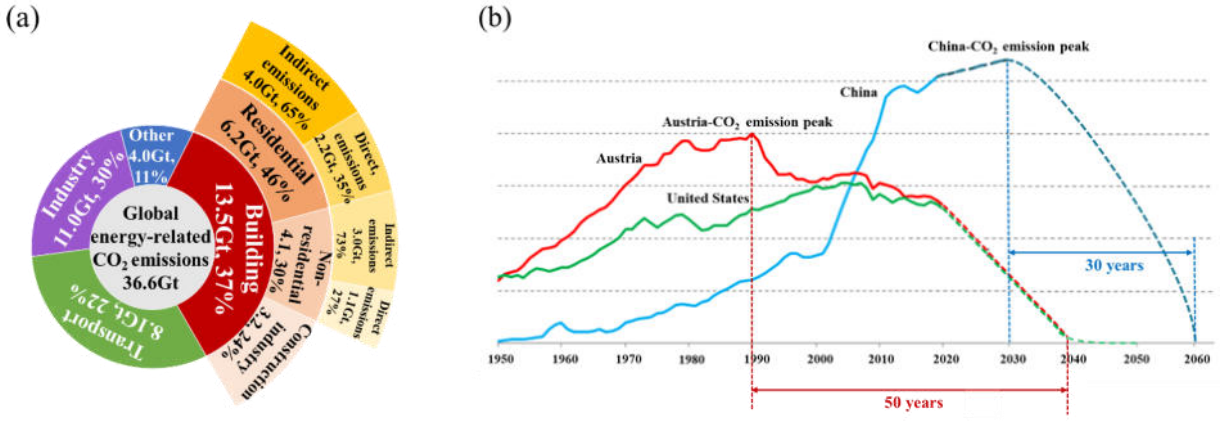


Fig. 1 Global carbon emissions: (a) Building sector global energy-related carbon emissions in 2021 [1]; (b) carbon peak and carbon neutrality trends: China vs. Austria [2]

This review is organized thematically to compare and synthesize literature on (a) renovation and decarbonization technologies, (b) carbon emission calculation methods, (c) legislative and regulatory frameworks, (d) market potential & barriers: China and Austria, (e) conclusion. We draw on peer-reviewed journals, conference proceedings, and authoritative reports. Major findings are summarized at the end, with a discussion of directions for building decarbonization in these regions.

RENOVATION AND DECARBONIZATION TECHNOLOGIES

CARBON EMISSION CALCULATION METHODS

LEGISLATIVE AND REGULATORY FRAMEWORKS

MARKET POTENTIAL & BARRIERS: CHINA AND AUSTRIA

CONCLUSION

REFERENCES

[1] United Nations Environment Programme, 2022, Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector.
[2] International Energy Agency, 2021, Global Energy Review: CO_2 Emissions in 2021.
[3] International Energy Agency, 2024, Strategies for Affordable and Fair Clean Energy Transitions.
[4] European Commission, 2020, Renovation wave initiative in the buildings sector,
[5] European Commission, 2024, Energy Performance of Buildings Directive adopted to bring down energy bills and reduce emissions.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
Sustainable Renovation and Energy Retrofits

DATA-DRIVEN ANALYSIS OF ENERGY EFFICIENCY AND OPTIMIZATION POTENTIALS IN A LOCAL LOW TEMPERATURE DISTRICT HEATING AND COOLING SYSTEM

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SUMMARY

This study investigates the potential for energy efficiency improvements and operational optimization in a local low temperature district heating network. A data-driven approach is applied, applying performance analysis to evaluate different configurations and operating strategies and seeks to identify the main factors influencing system performance and to evaluate the impact of varying heat source combinations and configurations on overall energy efficiency. Newly built houses meet high energy-efficiency standards, while existing buildings achieved around a 25% reduction in heating demand through targeted system and insulation upgrades. While heat pumps show high SPF values, the inclusion of auxiliary electricity causes a significant drop — highlighting the need for clear system boundary definitions. Real-world monitoring revealed that cooling is not active when heat pumps are running, usage varies strongly across buildings, and adapted hysteresis control was required during transition periods to prevent frequent switching between heating and cooling and to ensure energy-efficient operation.

INTRODUCTION

District heating and cooling systems combining different heat sources are increasingly seen as a key element of future-proof, efficient, and sustainable urban energy infrastructure. The integration of multiple heat sources — ranging from ambient and waste heat to renewable inputs opens up new possibilities for improving system efficiency and operational optimization but also adds complexity to local infrastructure. The findings are expected to contribute to the design of more efficient, flexible, and resilient district energy systems and support informed decision-making for planners and policymakers.

This contribution presents a residential settlement in Darmstadt, Germany, with six new multifamily dwellings (131 flats) and 12 existing dwellings (96 flats) and its integrated energy concept, focusing on the interaction of system components and initial results from on-site monitoring. The heating network is structured with multiple temperature levels and differentiated supply lines, allowing for efficient distribution and integration of low-temperature heat sources. The data collection conducted within this project is exceptionally comprehensive and detailed, rarely matched in other projects, and provides valuable insights into the operational behaviour of the heating network. Particular attention is given to the interplay between two heat pumps and a field of 22 geothermal borehole heat exchangers. The study also highlights the regeneration of the boreholes using waste heat recovered from a combined heat and power (CHP) unit and the low-temperature return flow of the buildings underfloor heating system. Previous analyses have demonstrated that the pump in the cold network exhibits considerable electricity consumption, while the heat pumps and the passive underfloor cooling (UC) are not operated simultaneously. Consequently, an in-depth investigation of the system's operational modes will be undertaken. Furthermore, the study will address the regeneration of the borehole heat exchangers through the

utilization of waste heat recovered from a CHP unit, in conjunction with the low-temperature return flow of the buildings' underfloor heating system. For the 2024-2025 summer period monitoring data several Key-Performance-Indicators will be accessed and evaluated.

METHODOLOGY

This study adopts a data-driven analysis based on two years of high-resolution operational data from the local district energy system. The present analysis places a particular focus on the characterization of the cold network, while maintaining a comprehensive view of operational patterns in heat pumps (HPs), underfloor cooling, and heat recovery (HR), with attention to the geothermal regeneration process and overall system operation, including the cold network pump and the CHP heat recovery unit (System components are depicted in Fig. 1). The first main objective is to investigate the influence of UC and HR on pump electricity consumption as well the seasonal performance factor (SPF) under different system boundaries, considering pump control, HR usage, and network losses. The second objective is to analyse the general operation of the cold network, evaluate its interactions with HPs and UC, and examine how HR is applied either for heat pump support or borehole regeneration under varying conditions. The objectives should develop a deeper understanding of the system operation in order to identify optimization potentials.

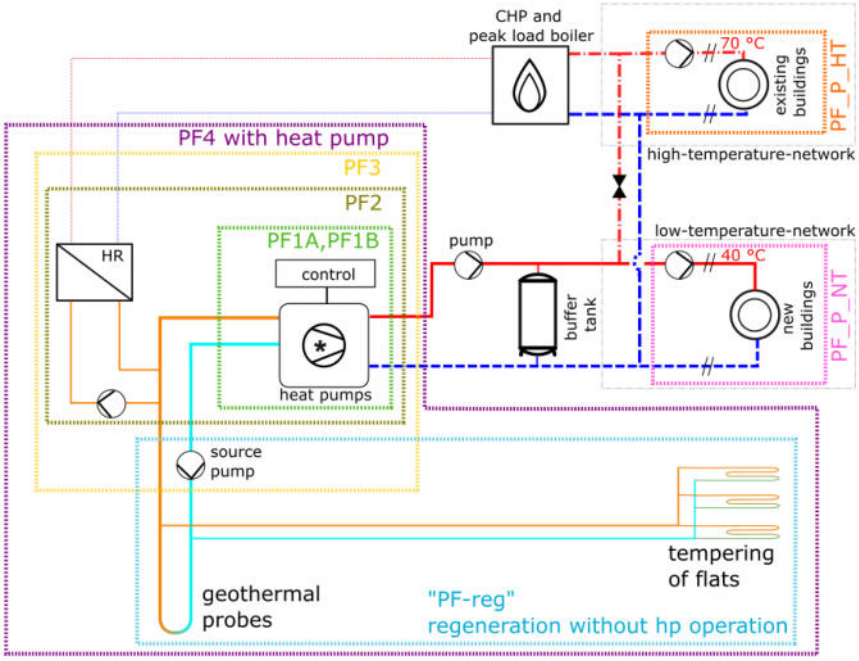


Fig. 1: Heat sources and sinks and corresponding performance factor (PF) system boundaries

Data Preparation, Feature Selection and Analysis Approach:
Operational data is aggregated at hourly and daily resolution to capture both short-term and long-term system dynamics. Descriptive statistics and time-series evaluation are used to quantify trends and identify recurring patterns in the system. Correlation analysis and conditional summaries provide insight into how specific operational modes of UC, HR, CHP, and the cold network pump influence HP electricity consumption, SPF, brine temperatures, and shares of regeneration. The approach emphasizes transparent and reproducible methods, focusing on direct insights from measured data rather than predictive modelling assumptions.

PRELIMINARY RESULTS

The newly constructed buildings were designed according to high energy-efficiency standards and, on average, meet the projected heat consumption values. In the existing building stock, heating demand was reduced by approximately 25% through targeted modifications to the heat supply system as well as the insulation of basement ceilings and top floors. Initial evaluations from intensive monitoring indicate that the SPF of the heat pumps appears to be very high. However, when considering the electricity consumption of all auxiliary pumps, the SPF drops to comparatively low values. This underscores the importance of carefully defining system boundaries by properly accounting for the energy flows of different components as 'inputs' and 'outputs' in efficiency assessments (Fig. 1). One potential optimization measure concerns the temperature difference between supply and return flow in the underfloor heating, which could be increased by adjusting the volume flow rates. In addition, the measured flow rates for underfloor cooling are very high, partly due to the fact that not all buildings are currently activated for cooling. Nevertheless, further operational aspects require attention. For instance, the operating schedules indicate that cooling is not active when the heat pumps are running. The PF4 (3,9) with auxiliary power only when the heat pump is running is only slightly lower than PF1 (4,2), while PF3 (3,0) is significantly lower. When the heat pump is running, the brine pump performance appears to function adequately, as it only has a slight effect on the coefficient of performance. When the heat pump is not running, the pump could possibly be speed-controlled and consume less power. Potentially, you could also check whether the pump speed can be reduced outside of heat pump operation to make summer regeneration even more efficient. Moreover, the utilization of the passive cooling function varies considerably across different buildings, a pattern that is still under investigation. During transition periods between heating and cooling, the implementation of an adapted hysteresis control for operation mode switching was necessary to ensure energy-efficient operation. Overall, valuable insights into the system's operational strategy have already been gained on the base of real-world data, and several potential optimizations have been identified.

DISCUSSION AND CONCLUSIONS

The preliminary results confirm that integrating diverse heat sources — particularly geothermal and CHP-based regeneration — can significantly improve the performance of the district energy systems. The system shows promising efficiency levels in real-world operation, especially the combination of the heating between existing and new building offers great synergy effects. A systematic review of hydraulic settings and flow rates after commissioning, together with verification of setpoints during transitional periods, represents a key element for further optimization and is likely transferable to other similar district energy systems. However, the analysis of the monitoring data will be continued until spring of 2026, to evaluate long-term stability, control strategies, and scalability.

REFERENCES

Project overview (German): https://www.iwu.de/research/energie/m-swivt/

CONFERENCE TOPIC

Future District Heating and Cooling Solutions

ACKNOWLEDGMENT

This study was conducted within the framework of the project "M-SWIVT - Monitoring phase on building modules for existing residential areas - impulses for networking energy efficient technologies" funded by the Federal Ministry for Economic Affairs and Climate Action

NUMERICAL EVALUATION OF A DYNAMIC MOVING PCM WALL FOR COOLING

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SUMMARY

Zero Energy Buildings (ZEBs) represent one of the leading solutions to reduce energy consumption in buildings, which are major energy consumers and are responsible for about 30% of global greenhouse gas emissions. In ZEB, facades are critical components. Adaptive façades, capable of responding dynamically to environmental changes, have garnered attention to enhance energy performance in ZEBs. This study focuses on the use of a dynamic moving Phase Change Material (PCM) wall as an adaptive façade system in Madrid (Spain). Traditional PCM walls have limitations in energy charging and discharging under varying conditions. Moving PCM walls overcome this by enabling energy release both inside and outside the building. The results indicate that implementing this system reduces the energy consumption by 145% in summer per square meter of wall.

INTRODUCTION

Climate change and environmental repercussions such as global warming and acid rain, considerable attention toward the building sector, as it is responsible for nearly 30% of global greenhouse gas emissions and one of the largest energy-consuming sectors according to the International Energy Agency (IEA)[1]. Moreover, in Europe, more than 40% of the total energy demand is dedicated to space heating and cooling. Hence, to address these concerns, Zero Energy Buildings (ZEBs) have introduced considerable interest as a suitable solution and following two goals, first, reducing energy consumption, and, second, cover almost all their energy requirements by means of renewable energy sources. As one of the most important challenges, fluctuations in climatic conditions throughout the day, across seasons, and over the entire year are faced by ZEB designers.

Among all available approaches, the dynamic moving phase change materials (PCMs) wall, first explained by de Gracia[2] significantly enhances energy efficiency despite its simplicity. This system is essentially an advanced version of incorporating phase change materials (PCMs) into walls and can be widely utilized in façades. Traditional PCM walls have limitations in energy charging and discharging under varying conditions. Dynamic moving PCM walls overcome by enabling energy release both inside and outside the building. Additionally, in this research, the system's performance is enhanced by the greenhouse effect generated by the addition of glass layers to the wall. This paper presents a numerical model including these thermal aspects and their impact on the performance of a moving PCM wall during the cooling season in Madrid (Spain).

METHODOLGY

In a traditional wall, the insulation layer acts as a thermal barrier to charge or discharge the PCM in its daily cycle. For example, in summer the insulation layer prevents the energy stored in the PCMs from being released to the outside, limiting at night its charging process for passive cooling applications. On the other hand, dynamic moving PCM wall technology will be able to make use of night free cooling by placing PCM facing outdoors at nightime to enhance the cooling charge of the PCM, and place it facing inside to prevent or delay the heat flux inside the room by means of its melting process. shows a schematic of the Moving wall’s performance.

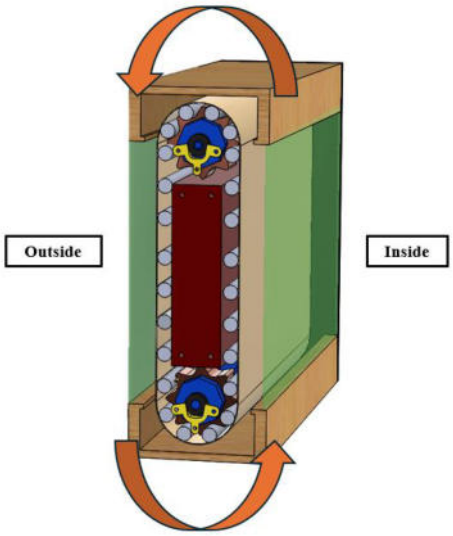


Fig. 8 Dynamic Moving PCM Wall performance

RESULT

The numerical result of the dynamic moving PCM wall is compared with a static PCM wall equipped with glass under summer weather conditions for 8 days. As shown in the **Fehler! Verweisquelle konnte nicht gefunden werden.**, Implementing a dynamic moving PCM wall has significantly decreased the cooling load compared to a Static PCM wall. The results obtained that by using this technology, energy consumption has changed from 0.965 kWh in static mode to -0.445 kWh in dynamic mode over the studied period per square meter of wall.

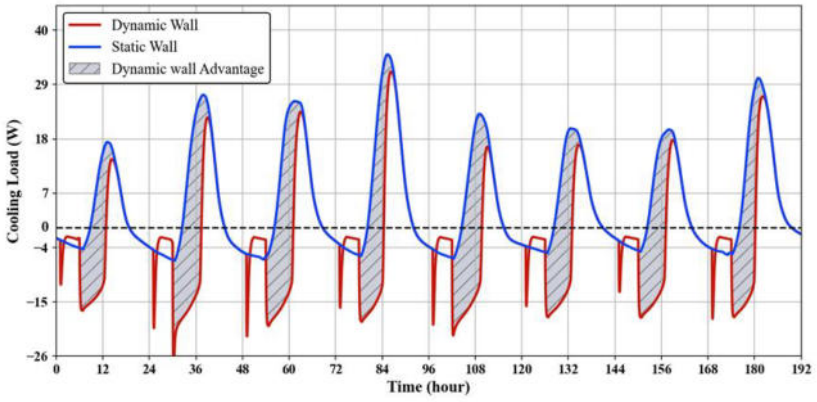


Fig. 9 Evolution of cooling load in the tested period (W)

REFRENCES

[1]IEA, Energy Technology Perspectives, paris, 2016.

[2] A. de Gracia, Dynamic building envelope with PCM for cooling purposes – Proof of concept, Appl Energy 235 (2019) 1245–1253. https://doi.org/10.1016/j.apenergy.2018.11.061.

CONFERENCE TOPIC

Smart Services and System Operation

REVOLUTIONIZING INDUSTRIES: ENERGY SYSTEMS FOR DECARBONIZATION THROUGH GEOTHERMAL INTEGRATION IN INDUSTRIAL PROCESSES

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SUMMARY

The industrial sector is a critical focus in the drive toward decarbonization, accounting for approximately 26% of the EU-27's final energy consumption and serving as the largest CO_2 emitter. Heating—predominantly reliant on fossil fuels—constitutes 60–70% of this energy use, with the remainder largely from electricity, including vapor-compression cycles for refrigeration and cooling. Recent years have seen a surge in research and development efforts to decarbonize and electrify industrial processes. Historically, heat pumps have had limited application in industrial contexts, but significant progress has been made in high-temperature heat pumps (HTHPs) for processes below 200°C. Moreover, thermal energy storage (TES) systems can enhance industrial heating and cooling decarbonization through greater flexibility.

The GeoS-TECHIS project integrates heat pumps and heat-driven refrigeration systems with medium-temperature geothermal sources and TES, building on the geothermal–industry binomial as a key pillar in the green transition of industrial energy systems with temperature requirements between 0°C and 200°C. It cascades heat utilization and rejection across the varying temperature levels needed by industries. This paper provides an overview of the project and presents some preliminary results.

INTRODUCTION

The GeoS-TECHIS project integrates heat pumps and heat-driven refrigeration systems with medium-temperature geothermal sources and thermal energy storage (TES), positioning the geothermal–industry synergy as a cornerstone of the green transition for industrial energy systems operating between 0°C and 200°C. The core concept employs cascading heat utilization and rejection tailored to industrial temperature needs, augmented by advanced digital tools for energy optimization and resource mapping.

A pivotal innovation is the AI-driven Geothermal Exploration Methodology (AIGEM), harnessing machine learning and deep learning to process diverse geo-datasets, including remote-sensing data. AIGEM reduces economic and risk barriers by enhancing prediction accuracy for energy yields and temperatures—up to 80% in validations—thus enabling more feasible geothermal deployments.

The project also prioritizes public acceptance of geothermal technologies via robust dissemination strategies, including stakeholder workshops, educational resources, and policy recommendations. These address societal and environmental concerns, adhering to the "do no significant harm" principle while ensuring impact transparency.

This paper overviews the project's integrated elements and shares preliminary findings from system modeling, TES optimizations, and AIGEM validations. Deep geothermal energy holds promise as a renewable industrial heat source but encounters major hurdles, such as deep drilling demands that drive up investments, prolong timelines, and elevate exploration risks. Despite R&D for cost cuts, deployment remains challenging.[1]

The subsurface temperature gradient (25–30 K km^{-1}) implies that direct heating at 150–200°C requires kilometers-deep drilling, where high-temperature resources favor electricity over process heat. Thus, emphasis shifts to shallower, lower- to medium-temperature resources (80–120°C), insufficient for direct industrial use. Shallow geothermal also inadequately serves as a heat sink for process refrigeration or air-conditioning.

1.1. GeoS-TECHIS Response to Challenge 1: Boosting Geothermal Utility

The project upgrades medium-depth, low- to medium-temperature heat to match industrial heating/cooling demands via an integrated thermal system functioning as a geothermal doublet. It extracts heat from deeper wells and rejects it to shallower sinks, enabling efficient heat-driven refrigeration cycles.

Industries endure variable daily thermal loads, rendering peak-sized medium-deep geothermal sources inefficient—escalating costs, environmental impacts, and failure risks.

1.2. Response to Challenge 2: TES for Flexibility

TES decouples geothermal harvesting from fluctuating demands, optimizing source sizing for decarbonization. Compatible with renewables and industrial waste heat, the TES design ensures adaptable, cost-effective operations. Underground TES (UTES) excels in dense industrial zones, providing compact, efficient storage. Rising renewables integration—marked by intermittency—compounds challenges with TES and variable loads, demanding fossil-free resilience. This is acute for capacity-optimized geothermal/TES in rapid-ramp processes, underscoring flexibility.

1.3. Response to Challenge 3: Digitalization for Management

Advanced monitoring, predictive analytics, and optimization—enabled by digital tools—will integrate assets like renewables, waste heat, and TES to meet needs. This aligns with the EU's goal: "becoming the first digitally enabled circular, climate-neutral, and sustainable economy, transforming its mobility, energy, construction, and production systems." [2] Geothermal exploration incurs high costs and uncertainties in assessing source quality and yields, even post-initial positives, deterring adoption.

1.4. Response to Challenge 4: Advanced Resource Mapping

AIGEM employs machine/deep learning to fuse geo-datasets (e.g., Copernicus remote-sensing), minimizing exploration uncertainties and pinpointing viable heat sources. By slashing economic/risk hurdles and respecting environmental limits, it bolsters sustainable production viability.

REFERENCES

[1] European Technology and Innovation Platform on Geothermal Energy (ETIP-Geothermal). (2018).
[2] European Commission, (2021), Horizon Europe strategic plan (2021-2024).

ACKNOWLEDGEMENTS

This article is part of the project GeoS-TECHIS, which has received funding from the European Union's Horizon Research and Innovation programme under Grant Agreement Nr 101172928

CONFERENCE TOPIC

Revolutionizing Industries: Energy Systems for Decarbonization through Geothermal Integration in Industrial Processes

CFD MODELING AND MULTI-OBJECTIVE OPTIMIZATION OF A SEGMENTED OPEN SORPTION HEAT STORAGE

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SUMMARY

This study presents a multi-objective optimization of a segmented open sorption heat storage reactor for building thermal energy storage. Since reactor performance depends strongly on geometry, flow distribution, and pressure drop, a detailed CFD model of coupled heat and mass transfer in a zeolite packed bed was combined with response surface methodology (RSM). A central composite design was used to sample the design space, and quadratic surrogate models were developed for seven performance indicators, including useful recovered energy, energy storage density, pressure drop, average mixed outlet temperature, outlet-temperature non-uniformity, and high-temperature delivery metrics. Based on ANOVA, diagnostic checks, and desirability-based optimization, an improved reactor geometry was identified and confirmed by direct CFD. The optimized design achieved higher useful energy and energy storage density, better outlet-temperature uniformity, and extended high-temperature delivery duration, with only a modest increase in pressure drop.

INTRODUCTION

The push for renewable energy in the residential sector is driven by the need to reduce CO_2 emissions. Among various strategies, thermal energy storage using materials like Zeolite 13X has emerged as a promising approach due to its ability to store and release heat efficiently over extended periods. Kuznik et al. developed a numerical model based on experimental data to study a zeolite 13XBF open heat storage system for building ventilation, evaluating desorption temperature, airflow rates, relative humidity, and bed thickness, with a discharging efficiency of 70% and overall efficiency of 36%. Mette et al. simulated two zeolite 13XBFK reactor designs: an integrated reactor within the storage reservoir and an external reactor requiring material transport. Simulations predicted a 36°C temperature increase (max 56°C) with 1.46 kW thermal power for the integrated design, and a 26°C increase with 860 W for the external reactor. Reichl et al. used CFD simulations, validated experimentally, to model an open sorption heat storage drum reactor. They observed enhanced airflow distribution and sorption efficiency within the drum reactor by addressing mixing, dead zones, and unused areas in the reactor. Among the possible reactor concepts, modular segmented open reactors are promising because they support scalability, use repeatable units, and can reduce pressure drop by shortening the flow path. However, segmentation can also create non-uniform flow, heat, and mass transfer, which leads to outlet-temperature imbalance and less reliable heat delivery. In addition, these effects are strongly coupled and difficult to optimize by trial and error. Therefore, this study develops a validated CFD–RSM framework to analyze these trade-offs and identify an improved reactor geometry for a realistic-scale segmented open sorption reactor.

RESULTS

The studied system is a segmented cylindrical open sorption reactor for thermal energy storage. The CFD model considers one representative module of the full reactor. This module includes the air-flow channel, internal segmentation, and zeolite packed bed, allowing the coupled heat and mass transfer during adsorption to be analyzed.

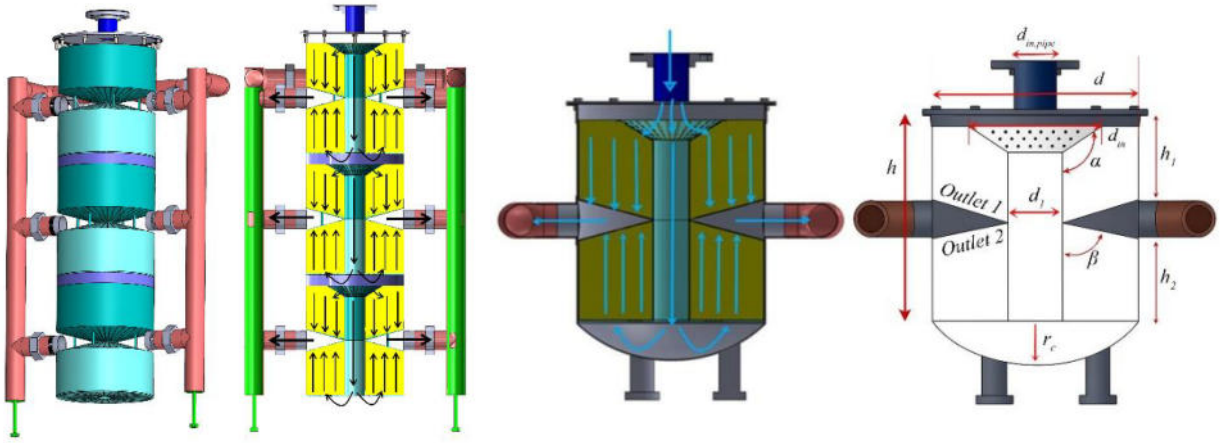


Figure 1. Modular reactor design (left) and Flow layout and geometry (right)

A transient 3D CFD model of one representative reactor module was developed in COMSOL Multiphysics 6.3 to simulate the coupled heat and mass transfer during adsorption in the zeolite packed bed. The model includes airflow, water-vapor transport, adsorption equilibrium and kinetics, and heat losses to the surroundings. All simulations used a uniform initial bed temperature of 30°C, an initial loading of 0.1 kg/kg, inlet and ambient temperatures of 30°C, outlet zero diffusive-gradient conditions, and wall heat loss to the surroundings. To reduce the cost of direct CFD-based optimization, a CFD–RSM framework was developed for the segmented reactor. Transient CFD data were used to build and validate quadratic surrogate models for multi-objective optimization. The models showed good agreement with the CFD results and provided a reliable basis for multi-objective optimization.

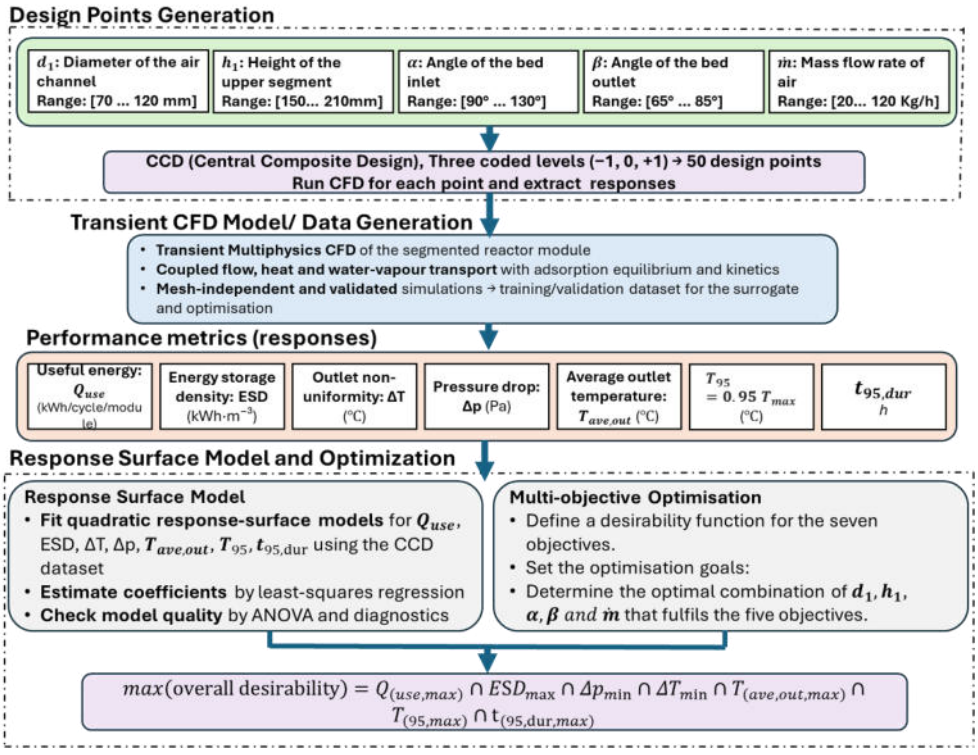
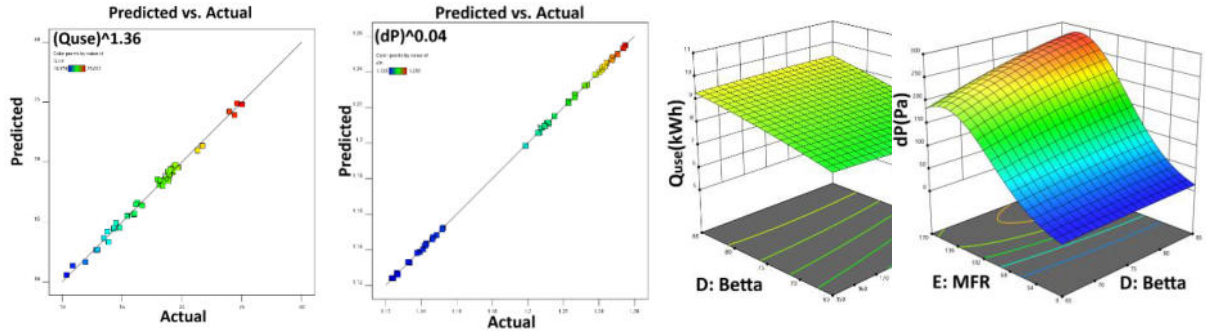


Figure 2. Workflow of the CFD–RSM framework and multi-objective optimization

Representative validation results for the surrogate models are shown in Figure 3 (a) and (b). For clarity, only two representative responses (Q_{use} and Δp) are presented here. For all responses, the surrogate predictions agree closely with the CFD results, with most points lying near the 1:1 line. Representative response-surface plots are presented here. For clarity, only two representative responses (Q_{use} and Δp) are shown for two selected variable pairs in Figure 3 (c) and (d). The plots illustrate the different sensitivities of thermal performance and pressure drop within the design space.



(a) (b) (c) (d)

Figure 3. Predicted-vs.-actual plots in (a) and (b), and representative response-surface plots in (c) and (d), for two representative responses.

Two representative overall desirability surfaces are shown to illustrate the optimization landscape. The h_1–β plane indicates a localized optimum, while the d_1–MFR($\dot{m}$) plane highlights the strong influence of mass flow rate on the final design compromise.

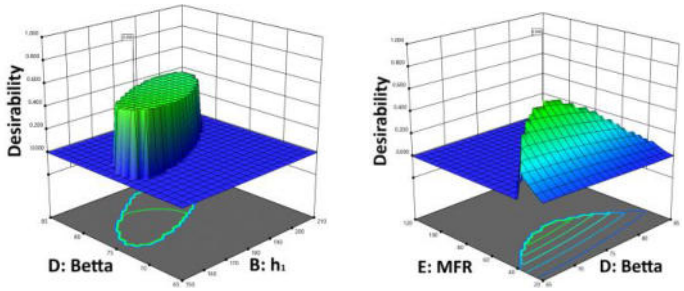


Figure 4. Desirability surfaces showing the effect of variable interactions on the optimal region.

The final optimum was found at $d_1 = 120$ mm, $h_1 = 155.7$ mm, $\alpha = 90°$,$\beta = 73°$,and $\dot{m} = 62.8$ kg/h. Direct CFD confirmation showed good agreement with the surrogate model for most responses, with errors below 3% for six of the seven indicators. The largest error was for ΔT, at about 10.8%. The optimized case exhibits a more uniform temperature field in Figure 5(a) and a more uniform water-uptake distribution in Figure 5(b), and the outlet temperatures become much closer, confirming strongly improved outlet-temperature uniformity, as illustrated in Figure 6 for the (a) reference design and (b) optimized design.

Reference design Optimized design

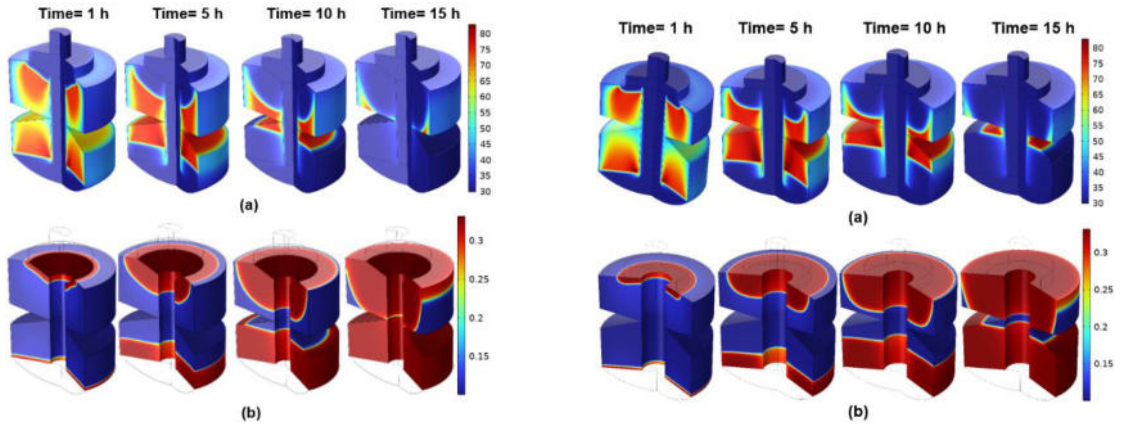


Figure 5. Comparison of the reference and optimized designs: (a) temperature field, (b) water-uptake

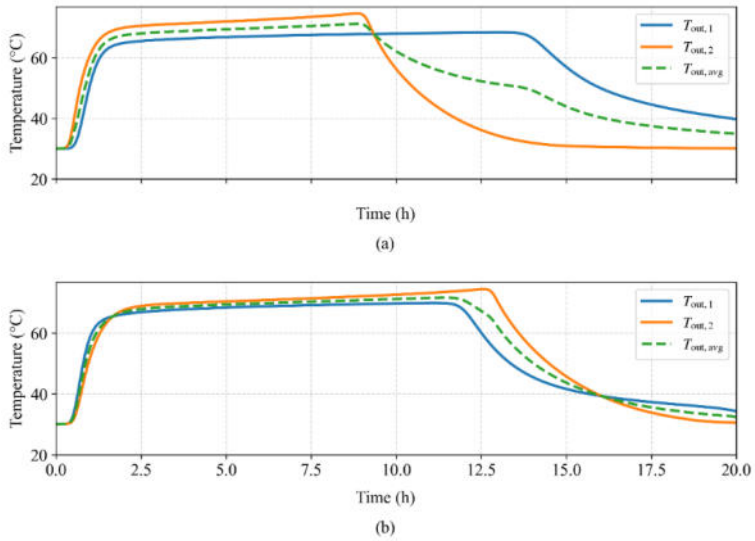


Figure 6. Outlet-temperature histories at the two outlets and their average for the (a) reference design and (b) optimized design.

The validated CFD–RSM framework successfully identified an improved segmented reactor design and was confirmed by direct CFD simulation. Compared with the reference case, the optimized design increased Q_{use} from 8.12 to 9.61 kWh (+18.28%), increased ESD from 141.56 to 148.93 kWh m^{-3} (5.21%+) , reduced ΔT from 13.18 to 3.92 °C (−70.3%), and extended $t_{95,dur}$ from 7.21 to 9.71 h (+34.6%), while Δp increased only moderately from 94.8 to 104.3 Pa (+10.0%). In addition, the average mixed outlet temperature increased from 52.45 to 57.48 °C (+9.59%) and T_{95} increased from 65.7 to 68.02 °C (+3.56%). Overall, the optimized geometry provided a clearly better balance between energy output, outlet-temperature quality, and hydraulic penalty.

REFERENCES

Kuznik, F., et al., (2019), Numerical modelling and investigations on a full-scale zeolite 13X open heat storage for buildings. Renewable Energy, 132, pp. 761–772.

Mette, B., Henninger, H. D., and Kerskes, H., (2014), Experimental and numerical investigations of different reactor concepts for thermochemical energy storage. Energy Procedia, 57, pp. 2380–2389.

Reichl, P. M., Zsembinszki, G., Demirkol, C., Lázaro, A., Cabeza, L. F., and Plesu, V., (2016), Fluid dynamics simulations for an open-sorption heat storage drum reactor based on thermophysical kinetics and experimental observations. Applied Thermal Engineering, 107, pp. 994–1007.

CONFERENCE TOPIC

1. Technologies and Systems for Buildings, Industry, Districts, Cities and Regions

1.06. Excess Heat and Resource Recovery from Low-grade Sources

1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

SEASONAL ENERGY STORAGE IN ALUMINIUM: SUPERHEATED STEAM ASSISTED ENERGY EXTRACTION

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SUMMARY

In the Reveal project (Revolutionary energy storage cycle with carbon free aluminium), we develop a sustainable energy storage and supply cycle using aluminium as an energy carrier. Surplus (electrical) energy is stored in the metal fuel over long times periods, while heat and H_2 can be extracted when or where energy is needed. Aluminium as a metal fuel, is one of the chemical carriers that is interesting for long-term chemical storage. It has high specific energy, good volumetric energy density, is highly abundant and can be sustainably recycled to close the material cycle. The energy supply phase (Alu-to-Power) comprises different ways to extract the stored energy in aluminium. In the presented work, we investigate the exothermic oxidation using superheated steam. This oxidation reaction yields Al_2O_3, with H_2 as an interesting side product. Alumina can be sustainably recycled using inert anode electrolysis cells (Power-to-Alu) to close the material cycle.
Keywords: Aluminium, Oxidation, Superheated steam, Hydrogen, Seasonal energy storage, Recycling

INTRODUCTION

Decreasing levelized cost of electricity from solar and wind drives the green energy transition in transport, buildings and industry towards using variable renewables (VRE). Due to inherent short- and long-term fluctuations, flexible energy storage and supply over different timescales and regions is crucial to supply energy when or where needed. Due to the increase of wind and solar in the electricity market, there will be a bigger tendency for surpluses and deficits on weekly, monthly or even seasonal timescales. These variations can be governed by fossil fuel carbon-based power or by ESS such as hydro (PHES or run-of-river), H_2 and biofuels. Currently there is lack of a sustainable long term ESS without technological, resource or geographical restrictions, which combines high energy capacity and volumetric energy density with convenient discharge times and long-term stability. Storing energy in a smartly chosen renewable and recyclable metal fuel, such as aluminium, can meet those requirements. Inert anode electrolysis opens up pathways to produce or recycle the fuel in a sustainable way. Cheap or surplus VRE electricity can be stored during production of aluminium (Power-to-Alu). Energy supply (Alu-to-Power) is achieved by exothermic oxidation of aluminium. The material cycle can be closed by recycling the oxidation reaction product into fresh aluminium in the Power-to-Alu phase. Domestic and off-grid energy supply becomes feasible when using larger sized aluminium fuel material. Combined, aluminium is a promising energy carrier for resolving both seasonal and geographical supply and demand energy imbalances.[1,2]

METHODOLOGY

While adding to its long-term stability, a native and dense passivation layer hinders oxidation and energy extraction from the fuel. In the presented work, the aluminium is activated using superheated steam. Reactive ions in the steam are adsorbed and can penetrate the protective passivation layer, also for larger granulate matter.

This results in complete exothermic oxidation of aluminium fuel in a dry reaction medium by using superheated steam as oxidizing agent. H_2 is generated as an interesting energy carrier during the process.[3]

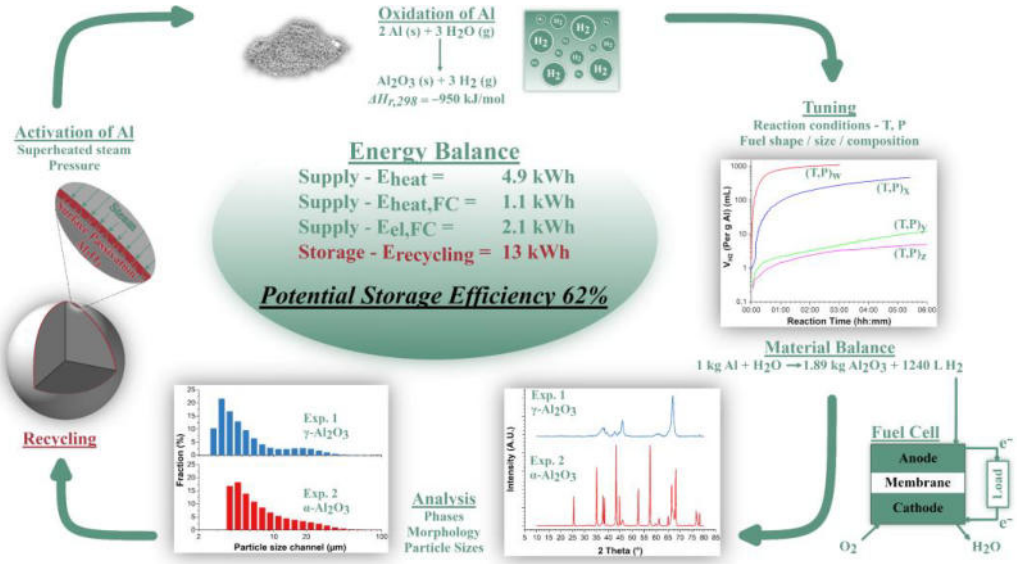


Figure 37: REVEAL energy storage cycle using superheated steam in the Alu-to-Power cycle

RESULTS

A batch reactor with continuous steam production was used for the oxidation of aluminium. The reaction was monitored in situ by the evolution of H_2 gas. Changes in mass, morphology and chemical composition are evaluated to gain insights into the reaction pathway (Figure 37). Reaction conditions, state of matter, dimensions, shape and composition of the fuel influence energy extraction during Alu-to-Power. Full conversion, and thus maximal energy extraction, were reached for temperatures above 450 °C and pressures above 30 bar, depending on the fuel material. Understanding the Al_2O_3 material in terms of phase composition, morphology and particle sizes will help to optimize the energy efficiency during Power-to-Alu. Solubility in cryolite for different Al_2O_3 phases with various particle size distributions is crucial. Transition Al_2O_3 phases, such as γ/δ/θ, are favourable in the recycling feed, as they have better solubility than the thermodynamically stable α-Al_2O_3 phase. For particle size, a compromise between good wetting and dissolution of Al_2O_3 on one side and reliable feeding without handling problems on the other side, is required to optimize the recycling phase.
With a targeted energy storage and supply efficiency of 62%, this aluminium fuel based ESS shows high potential to flexibly cover seasonal energy demands.

FUNDING

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REFERENCES

(1) Bergthorson, J. M. Recyclable Metal Fuels for Clean and Compact Zero-Carbon Power. *Progress in Energy and Combustion Science* **2018**, *68*, 169–196. https://doi.org/10.1016/j.pecs.2018.05.001.
(2) Haller, M. Y.; Amstad, D.; Dudita, M.; Englert, A.; Häberle, A. Combined Heat and Power Production Based on Renewable Aluminium-Water Reaction. *Renewable Energy* **2021**, *174*, 879–893. https://doi.org/10.1016/j.renene.2021.04.104.

(3) Van de Velde, N. W.; Drinčić, A.; Grom, M.; Likozar, B.; Genorio, B.; Haller, M.; Jerman, I. Activating Aluminium for Oxidation and Hydrogen Release: Overcoming the Passivation Barrier with Superheated Steam. *[Unpublished manucript, submitted]* **2025**.

CONFERENCE TOPIC

1.12. Next-Generation Technologies for Renewable Energy and Resource Efficiency

FROM HEAT DEMAND TO ENGAGEMENT: MAPPING SOCIO-TECHNICAL CONDITIONS FOR URBAN ENERGY PLANNING

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SUMMARY

This contribution presents a spatial analysis approach that integrates heating supply suitability and socio-demographic typologies to identify transformation potentials for the urban heat transition. Based on 100 m × 100 m grid data from Bremen (Germany), zones of technical supply options (district heating, LowEx heating network, single supply) are intersected with Sinus-Milieu distributions. The resulting maps highlight where technical feasibility aligns or conflicts with residents' lifestyles and participation preferences. This enables targeted, milieu-specific engagement strategies and more effective spatial planning. The approach demonstrates how integrating sociological segmentation into energy planning can enhance the social responsiveness of transition strategies. As an optional extension, building-level efficiency indicators (e.g. worst performing buildings) may be incorporated to refine prioritization.

Keywords: Urban heat transition; Spatial energy planning; Socio-technical integration; Sinus-Milieus; Citizen engagement; GIS-based analysis

INTRODUCTION

Decarbonizing urban heating systems is a key challenge for sustainable city transformation. While technical solutions are widely available, their implementation depends on both spatial feasibility and social context. This contribution introduces a spatial analysis that combines demand driven heating supply suitability with lifestyle-based socio-demographic data to generate differentiated socio-spatial profiles. Rather than prescribing specific measures, the approach aims to support local stakeholders in identifying appropriate engagement strategies with chances of resonating at the neighbourhood level, such as incentives, outreach formats, or planning priorities. The city of Bremen (Germany) serves as a case study.

METHODOLOGY

The analysis is based on geospatial data aggregated to a 100 m × 100 m grid (BKG, 2019) across the urban area of Bremen. Heating demand estimates (DBI Gruppe, 2024) were used to derive suitability zones for different supply options, such as district heating, LowEx networks and single supply (Knies et al, 2024a). In parallel, building-level data on dominant Sinus-Milieus (Küppers, 2024) were aggregated to the same grid, weighted by the number of households per building. This yielded a spatially coherent layer of lifestyle-based socio-demographic profiles, enabling the intersection with technical supply zones and the creation of differentiated socio-technical urban typologies.

RESULTS

Building on previous work (Schwarz et al., 2025), the aggregated Sinus-Milieus were first directly linked to heat demand on the same 100 m × 100 m grid. Initial outputs include 3D visualizations showing correlations between dominant milieu types (color) and absolute heat demand (bar height), as shown in Figure 1. These visual tools already highlight distinct socio-spatial patterns. To refine the analysis, additional indicators such as population count (Destatis 2024) and heated reference area (Eikmeier et al., 2021) were used to calculate specific heat demand per cell. The core contribution of this study, however, lies in intersecting the derived heating supply suitability zones, based on calculated linear heat densities (Knies et al., 2024b) with the socio-demographic milieu distribution. This final step enables spatially explicit interpretations of where certain supply options meet particular lifestyle contexts, thus informing further engagement, planning, or prioritization by municipal actors.

Preliminary results from this geospatial analysis step are still subject to validation and will be further refined for effective visual communication, but are not yet included in this abstract.

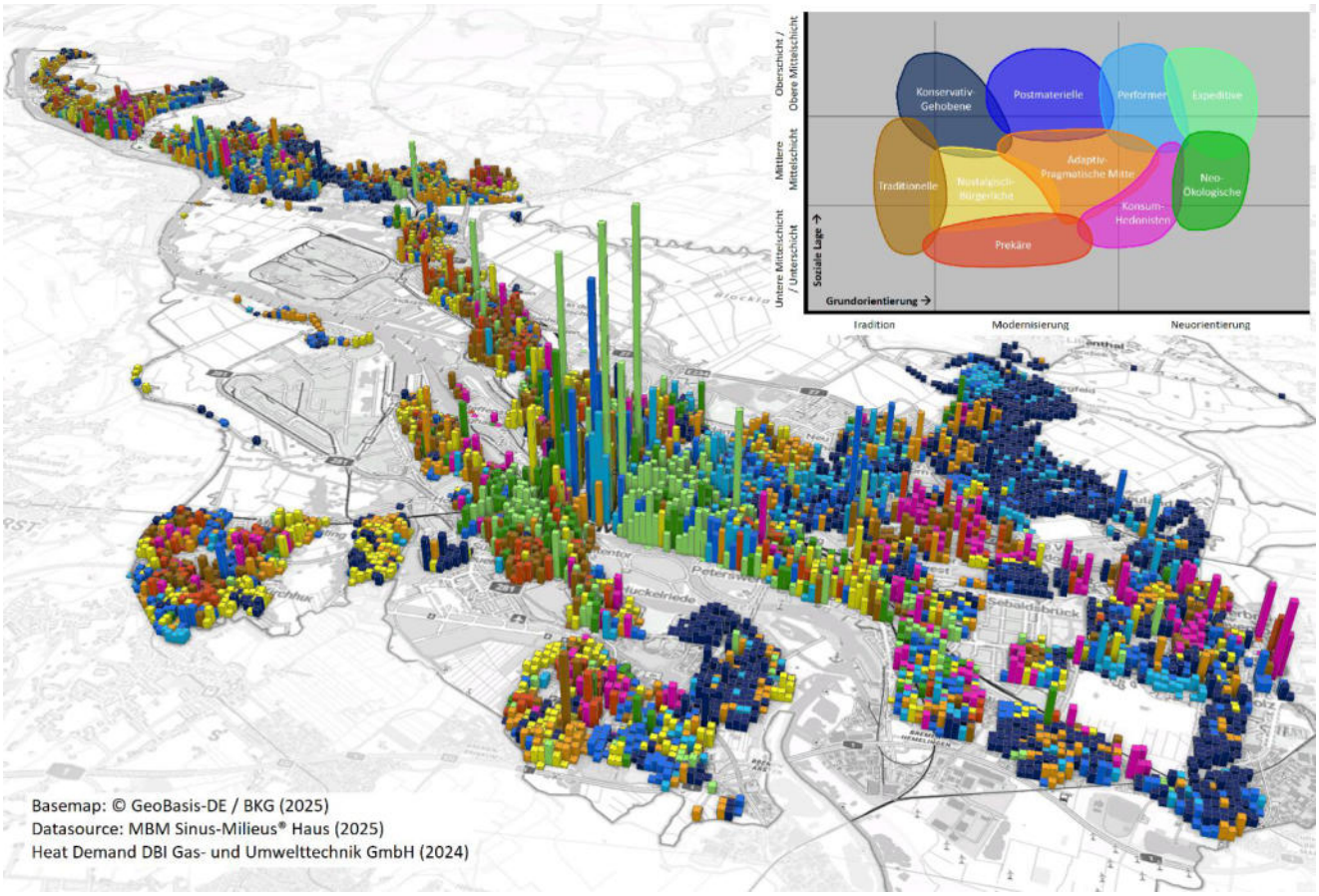


Fig. 1: 3D visualization of aggregated (100 m × 100 m grid) dominant Sinus-Milieu types (color) and absolute heat demand (bar height) for residential buildings in Bremen

CONCLUSION

This contribution demonstrates how combining heating supply suitability with socio-demographic segmentation can enrich urban energy planning. By revealing the socio-spatial conditions under which specific supply strategies may succeed or face resistance, the method provides a foundation for more targeted, context-sensitive engagement and decision-making. While the approach does not prescribe concrete measures, it offers planners and stakeholders a differentiated perspective on transformation potentials – one that acknowledges both infrastructural and social complexity in the heat transition.

ACKNOWLEDGMENTS

This work is part of the „Wärmewende Nordwest“ research project. The author would like to thank the German Federal Ministry of Research, Technology and Space for funding the project Wärmewende Nordwest – Digitalisierung zur Umsetzung von Wärmewende- und Mehrwertanwendungen für Gebäude, Campus, Quartiere und Kommunen im Nordwesten - Arbeitspakete: Potentiale für eine stadtweite und quartiersbezogene Transformation der Wärmeversorgung sowie Bildungsformate für nachhaltige Entwicklung (funding code: 03SF0624H)

REFERENCES

BKG, Bundesamt für Kartographie und Geodäsie (2019), Geographische Gitter für Deutschland in Lambert-Projektion (GeoGitter Inspire). Online available: https://gdz.bkg.bund.de/index.php/default/geographische-gitter-fur-deutschland-in-lambert-projektion-geogitter-inspire.html

DBI Gruppe (2024), DBI-Ansatz zur Modellierung von Wärmebedarfen. Forschungsbericht. https://www.dbi-gruppe.de/waermebedarf_zukunft

Destatis, Statistisches Bundesamt (2024), Zensusdatenbank: Zensus 2022. Online available: https://ergebnisse.zensus2022.de/datenbank/online/

Eikmeier, B., Janßen, K., Wassermann, T. & Meyer, B. (2021), Erstellung eines Wärmeatlas für Bremen und Bremerhaven. Bericht Ist-Analyse. Bremen. Online available: https://www.wesernetz.de/-/media/wesernetz/downloads-aktuell/fuer-mein-zuhause/zuhause-nachhaltiger/fernwaerme/waermeatlas/bericht_ist_analyse_wesernetz_15102019.pdf

Knies, J., Gerling, Y., & Heinrich, P. (2024a), Ein ArcGIS-Pro-Modell zur Ermittlung von Eignungsbereichen für Wärmeversorgungsoptionen (Version 1). Zenodo. Online available: https://doi.org/10.5281/zenodo.10675339

Knies, J., Heinrich, P., Steyer, N., Gerling, Y. & Schwarz, T. (2024), Ein ArcGIS-Pro-Modell zur Ermittlung von Eignungsbereichen für Wärmeversorgungsoptionen am Beispiel der Stadt Bremen. Online Available: https://doi.org/10.26092/elib/2640

Küppers, R., (2024), Übertragung in den Raum: Die Sinus-Milieus® in der Microgeographie. In Praxis der Sinus-Milieus®: Gegenwart und Zukunft eines modernen Gesellschafts- und Zielgruppenmodells, B. Barth, B. B. Flaig, N. Schäuble und M. Tautscher, (publishers), Wiesbaden: Springer Fachmedien Wiesbaden, 2024, S. 133–147.

Schwarz, T., Gerling, Y. & Knies, J. (2025), Bürgerschaftliche Potenziale: Akteursidentifikation und -aktivierung in der Wärmewende – Aktualisierung der Sinus-Milieus® für Bremen. In 14. BUIS-Tage 2025 in Oldenburg, VLBA UOL (publisher), Shaker Verlag. *[in publication]*

CONFERENCE TOPIC

Transform Cities: Holistic Approaches to Sustainable Urban Energy

EVALUATION OF THE SEASONAL ACCURACY OF THERMAL ARRAY SENSORS FOR OCCUPANCY-BASED CONTROL SYSTEMS

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SUMMARY

The use of sensors-based building automation can help to reduce energy consumption and comfort in buildings. In this context, thermal array sensors are a promising option for providing occupancy-related information in smart buildings, such as presence status, number of people and position, in compliance with data protection regulations. The specific applications and expected accuracy of this well-established technology still need to be clarified. To highlight the accuracy and reliability of the technology, a technical-functional system evaluation was carried out in a structured laboratory study with 60 participants. A six-month field study in an office examined how seasonal temperatures affect sensor performance. Results show high accuracy in winter, but reduced precision in summer due to lower temperature contrasts, requiring longer switch-off times for building services. A simple lighting simulation shows potential energy savings. This study underlines the relevance of thermal array sensors for data protection-friendly and adaptive building control.

INTRODUCTION

Energy-efficient building operation is based on using energy only where it is actually needed. In larger office applications designed for several people, ventilation and lighting can be zoned and thus controlled in an energy-efficient manner (cf. (Hammes et al., 2020). Compared to manual control, the use of such sensors can save around 30 % energy (Galasiu et al., 2007). In addition to separately controllable actuators, this also requires the collection of relevant measured variables. These include occupancy detection and knowledge of the position of people. Due to their low cost and ease of installation, passive infrared (PIR) sensors are most commonly used for detection (Guo et al., 2010), but multiple applications are required to obtain further information details. In addition, there are limitations in terms of accuracy, which can be seen in false-off rates (Maniccia et al., 1999). In order to determine the number of people and their position via a single sensor, imaging sensors are gaining in importance, but they are not widely accepted. Thermal array sensors represent an innovative and data protection-compliant technology in this context, as they only detect thermal differences and do not record any personal characteristics.

The objective of this work is to analyze the potential of thermal array sensors for detecting presence, number of people and position in a room. The aim is to examine how precisely the information can be detected in a room and how reliably thermal sensors work under different environmental influences and can provide the necessary information for building services systems. The accuracy determines the necessity and length of follow-up times. For passive infrared sensors, the industry standard is around 15 minutes. This can be further reduced by adapting to individual usage patterns (Hammes et al., 2021). The study therefore examines which run-on time strategies are required for thermal array sensors and how these differ between summer and winter conditions. In order to test how well these sensor technologies, perform in terms of energy, a simulation is carried out to control the electrical lighting, which is compared with conventional sensor technology. Transferability to other trades is possible.

METHODOLOGY

A comparison of various presence and position detection methods revealed differences in accuracy and robustness between rule-based and machine learning approaches. As part of a structured one-week laboratory study, a 30 m² office at the University of Innsbruck was set up so that 60 study participants (max. 4 at a time) completed a series of tasks imitating typical office work. This enabled an evaluation of reliability and accuracy in configurations with different distances, as well as the simulation of temporary absence. Detection was performed using 32x32 thermal array resolution sensors (Omron, D6T-32L-01A) mounted on the ceiling. Detection accuracy was evaluated against ground truth data. In addition, a questionnaire was conducted by the study participants to evaluate this technology in comparison to alternative occupancy detection methods. In a six-month field study at the University of Innsbruck, long-term use, interference effects, and seasonal differences were examined. To better assess boundary conditions, contrast in classical IR images was analyzed and compared with controlled lab scenarios. From this, the detection quality and a suitable switch-off time was determined. A control system for occupancy-based lighting control was simulated to evaluate the potential energy savings.

FINDINGS FROM THE STUDY

Threshold-based methods as well as regression with deep learning and decision trees are suitable for deriving the presence status, number and position of occupants. The laboratory study shows that very high accuracy can be achieved in occupancy and position detection under controlled conditions. The field study also identified significant differences between the seasons in terms of accuracy. While reliable real-time detections with a very low error rate were possible in winter, the detection quality and thus also the follow-up time deteriorated considerably in summer due to lower temperature contrasts. This additional influence on the artificial light energy requirement is relativized by higher daylight availability in summer. Overall, the thermal array sensor leads to more energy-efficient operation compared to other detection methods that generate a reduced information content. In the questionnaire, the study participants rated the acceptance significantly higher than camera systems and comparable with conventional passive infrared sensor technology. Data protection concerns in particular were considered to be comparatively low with this technology. Additional heat sources such as active computers could be filtered out as interfering influences using rule-based filter processes. Accordingly, thermal array sensors offer great potential for intelligent and sustainable use in modern building technology.

REFERENCES

Galasiu, A.D., Newsham, G.R., Suvagau, C., Sander, D.M., (2007), Energy Saving Lighting Control Systems for Open-Plan Offices: A Field Study, LEUKOS 4, 7–29.
Guo, X., Tiller, D., Henze, G., Waters, C. (2010), The performance of occupancy-based lighting control systems: A review, Lighting Research & Technology 42, 415–431.
Hammes, S., Weninger, J., Canazei, M., Pfluger, R., Pohl, W., (2020), Die Bedeutung von Nutzerzentrierung in automatisierten Beleuchtungssystemen, Bauphysik 42, 209–217.
Hammes, S., et al., (2021), Reduzierung des Kunstlichteinsatzes durch Anpassung der Nachlaufzeit an individuelle Anwesenheitsmuster. Bauphysik 43, 50–64.
Maniccia, D., Rutledge, B., Rea, M.S., Morrow, W., (1999), Occupant Use of Manual Lighting Controls in Private Offices, Journal of the Illuminating Engineering Society, 28(2), 42–56.

CONFERENCE TOPIC

Smart Services and System Operation; IT Solutions and Artificial Intelligence.

OCCUPANT COUNTING AND POSITION DETECTION VIA MACHINE LEARNING ON MULTIMODAL IMAGE DATA

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SUMMARY

High-resolution presence information is proving to be essential for increasing energy efficiency and improving user comfort. However, such data must go beyond mere presence information. Camera systems can provide such data. This study investigates the extent to which multimodal camera data can be used to augment the binary presence status in buildings with information on the number and position of people. The added value of increased accuracy in presence detection and positional information lies in enabling more precise and adaptive control strategies, whose effectiveness is strongly influenced by the size of the room. Accuracy and reliability of data stream related machine learning models are compared against ground truth data from a structured laboratory study. All models show high accuracies. Region-of-interest segmented analysis facilitates precise localization. Convolutional Neural Network proves to be advantageous for person recognition. The implementation on a resource-constrained edge-device enabled fully decentralized processing.

INTRODUCTION

Occupancy patterns are considered to be one of the most important factors influencing building energy demand (Yoshino et al., 2017). Taking occupancy patterns into account is therefore essential for energy-efficient system operation. Automated control systems are usually used, as these prove to be more energy efficient than manual systems (Chew et al., 2017). Since working from home, flexible working time models and work process dynamics (e.g., meetings) can lead to highly variable usage patterns of the workplace, generally applicable schedules for building control may not prove to be expedient (cf. Hammes et al., 2021). Sensor-based systems are used to obtain the necessary information. Although passive infrared sensors are convincing due to their low installation costs, they are associated with switch-off times in order to avoid false-off rates. Other detection methods also have risks of incorrect detections, e.g., false-on with ultrasonic sensors. In addition, most sensing technologies have a limitation in information content and usually only provide binary state information. CO_2 sensors offer the possibility to derive information about the quantity, but this technology is associated with inertia, which prevents its use for real-time reactive systems such as lighting (Salimi and Hammad, 2019). Additional information is proving to be essential for energy efficiency and comfort objectives (Chew et al., 2017).

Camera systems offer the possibility of capturing several types of information in high resolution. In addition to more precise presence, the location information in particular promises advantages for building technology. The use of a small number of sensors that can record all relevant input variables also promises low complexity and installation costs. The disadvantage is that these methods are usually computationally intensive and are viewed critically in terms of data protection (Salimi and Hammad, 2019). Concerns could be reduced if relevant parameters are processed in a time step without storing image information.
The objective of this work is therefore to investigate the extent to which different data streams from a multimodal camera can be used to extend a simple binary presence status to include the number of users and their position.

In particular, the study explores the added value of increased accuracy in presence detection and positional information for building control, considering the decisive role that room size plays in the relevance and impact of this information. The objective is to examine which models are best suited for which data streams in order to ensure high accuracy and reliability.

METHODOLOGY

Color image, depth image and infrared image (all via Intel RealSense depth camera D435) as well as discretely captured single images (Seeed studio, Xiao ESP32S3, OV2640) are used in combination with different machine learning models to ensure reliable detection of the number and position of people within a building. Different models are evaluated for accuracy, robustness, and runtime, with a focus on edge-device feasibility to meet technological and data protection requirements. Motion filtering limits frame analysis to reduce the computational load. Efficient detection is ensured by a lightweight CNN, while MoveNet-based skeleton tracking improves localization and temporal consistency. All processing is done locally, and no image data is stored or transmitted. The accuracy and reliability of the individual methods are compared using ground truth data from a controlled laboratory study. To evaluate the added value of positional information, the accuracy and energy-efficiency potential of the camera-based approach are compared to traditional PIR-based sensing with the same objectives, using simulation-based analysis across different zoning concepts and room sizes. An acceptance study with 60 test subjects compared this technology with alternative occupancy detection methods.

FINDINGS FROM THE STUDY

The study shows that while all data streams (color, depth, infrared and single images) enable reliable real-time person detection and high accuracy, the added benefit of improved accuracy over PIR sensors for simple presence detection is low. However, camera systems are clearly superior to PIR sensors when multiple independently controllable zones are present, as they are able to more accurately localize people with high accuracy using region-of-interest segmentation and skeleton tracking with depth data without additional sensor deployment. The implemented pipeline includes frame extraction, motion detection, YOLO-based person detection, and MoveNet skeleton tracking. It runs fully locally on resource-limited edge devices and was positively evaluated in terms of data protection.

REFERENCES

Chew, I., Karunatilaka, D., Tan, C.P., Kalavally, V., (2017), Smart lighting: the way forward? Reviewing the past to shape the future, Energy and Buildings 149, 180–191.
Hammes, S., et al., (2021), The impact of occupancy patterns on artificial light energy demand - simulation and post-occupancy-evaluation. Building Simulation Conference Papers Vol. 17, Proceedings of the 17th IBPSA Conference Bruges, Belgium, Sept. 1-3, 2021. 3536-3543.
Salimi, S., Hammad, A., (2019), Critical review and research roadmap of office building energy management based on occupancy monitoring, Energy and Buildings 182, 214–241.
Yoshino, H., Hong, T., Nord, N., (2017), IEA EBC annex 53: total energy use in buildings—analysis and evaluation methods, Energy and Buildings 152, 124–136.

CONFERENCE TOPIC

IT Solutions and Artificial Intelligence; Smart Services and System Operation.

GUIDELINES FOR PROJECT EVALUATION AND SITE SELECTION FOR GROUND-MOUNTED SOLAR THERMAL SYSTEMS

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SUMMARY

How can the share of renewable energy, especially solar thermal energy, in district heating networks be increased? A new guideline offers practical tips for project evaluation and site selection for ground-mounted solar thermal systems. The guideline was field-tested in the Lower Austrian towns of Deutsch-Wagram and Stockerau and highlights the technical, legal, economic, and funding-related aspects to consider. The lessons learned from the field test have been incorporated into the guideline, which is of special interest for local authorities, heat network operators and planners. It is the first guideline for ground-mounted solar thermal systems; previously only guidelines for ground-mounted photovoltaics have been available.

INTRODUCTION

Currently, 1.2 million households in Austria heat with district heating. The share of renewable energy in district heating was just under 60% in 2021, solar thermal energy can make a significant contribution to increase the renewable share, as the most climate- and environmentally friendly technology of all. As of 2024 there are only around a dozen large ground-mounted solar thermal systems in operation. There is a great need to catch up with these systems. One obstacle is a lack of know-how transfer to the construction of future ground-mounted systems in other cities based on the knowledge of the existing ones.

Large ground-mounted solar thermal systems have different requirements than photovoltaic systems, regarding planning and legal framework. To spread these systems, sound technical and legal criteria are needed for local authorities, heat network operators and planners to proceed with project evaluation, site selection and permitting processes. The new guideline offers practical tips on this.

IMPORTANT STEPS FOR IMPLEMENTATION

For the success of ground-mounted solar thermal systems, the early involvement of key stakeholders is essential, especially municipal representatives, heat network operators, local planners, and project developers. It has proven useful to organize a field trip with these stakeholders to existing ground-mounted systems to gain practical experience with the technology, system integration, impacts on the landscape, consideration of environmental regulations, etc. This makes a ground-mounted solar system clearer and more tangible for all involved; objections, concerns, and expectations are articulated, and individual adaptations to the specific project are discussed. Ideally, this process provides the basis for positive decision-making and subsequent project implementation. A typical decision-making process for a ground-mounted system is described in detail in the guideline.

CRITERIA FOR PROJECT EVALUATION AND SITE SELECTION

Ground-mounted systems should generally be built in close proximity to the central heating boiler and the heating grid. Should the solar system cover only the summer load in the grid or also contribute to the heating load in winter? Is a standard collector setup or an agri-solar setup desired due to additional agricultural land use between the collector rows? These requirements must first be clarified. The most important prerequisite for planning is the energy supplier's fundamental interest in solar supply in the heating grid. Equally important is clarifying who could be considered as the investor and operator of the system. A key prerequisite of the project evaluation is comprehensive data collection, the results of which provide an initial estimate of location, size, and space requirements, as well as solar yield and profitability.

SPATIAL AND LEGAL REQUIREMENTS

In addition to technical criteria, spatial and legal suitability criteria must also be considered in site selection for ground-mounted systems. Particularly due to the size (several thousand square meters), there are potential conflicts with other land-use requirements. Potential locations for ground-mounted solar thermal systems are always located close to residential areas. Therefore, coordination with local spatial planning authorities is important. In order to obtain a permit under nature conservation law, it is recommended to draw up an overall ecological concept that is based on nature conservation and species protection law requirements. In addition, spatial planning permits, a building permit, and a commercial license must be obtained. The regulations vary in each federal state; this is the case in Austria, but also in many other countries.

FIELD-TEST OF THE GUIDELINE AND LEARNINGS

To test the guideline in practice, the planning of a ground-mounted solar thermal system was carried out in the towns of Deutsch-Wagram and Stockerau. The planning was carried out in close coordination with the municipality, local planner, and utility, as recommended in the guideline. The system planning and site search in both towns resulted in the identification of suitable sites near the heating plant that could cover 80% of the heating network's summer load. The guideline has proven to be a helpful support in both towns; the next step is discussions with the affected property owners. The guideline is an important tool for local authorities, heat network operators, and planners in promoting ground-mounted solar thermal systems.

REFERENCES

Austria Solar (2025): Guidelines for project evaluation and site selection for ground-mounted solar thermal Systems, Vienna

CONFERENCE TOPIC

Support Schemes for Implementation in Buildings, Industry, Districts, Cities and Regions – Marketing, dissemination and implementation strategies

SODIUM-ION BATTERIES FOR ALTERNATIVE BATTERY STORAGE SYSTEMS

E. Povoden-Karadeniz

Research on alternatives to Li-ion batteries for energy storage are widely spread to date. This involves not only the question of functionality, but also costs and sustainability for a competitive materials selection. Sodium-ion batteries represent a promising, sustainable and lower-cost alternative to lithium-ion batteries, employed particularly in grid-scale storage within Battery Energy Storage Systems. Computational materials engineering in the spirit of Applied Calphad provides the fundamental understanding of phase stabilities within cathode and electrolyte oxide, as well as anode alloy, as function of temperature, composition, oxygen partial pressure (reflecting the thermodynamic redox behavior of functional materials), and defect chemistry. In terms of materials, optimisations concern the cathode oxides, where the manner of charge carrier transport can change as function of phase compositions and temperatures. A systematic thermodynamic description is provided. The optimisation of electrolytic, long-term applied “Nasicon” (sodium superionic conductor) can lead to decreasing number of involved elements at same functionality. A respective description is also provided, and finally an Sb-based anode with Bi and Sn alloy is discussed. Recent battery research has shown that the electrochemical preformance ot this alloy is outstanding. Here, its stability is shwon by the phase diagram of Sb-Bi-Sn-(Na), which is designed computationally, based on recently available enthalpies of mixing.
The documented system represents a complete setup of the fundamental thermodynamic state variables of the phases comprising the system Na-Mn-O, Na-Y-Zr-O, and Sb-Bi-Sn alloy interacting with Na, applicable to future Na-battery setups for alternative and sustainable energy storage.

A REVIEW AND CLASSIFICATION OF AGEING MODELS FOR DISTRICT HEATING (DH) PIPELINES: DETERMINISTIC, PROBABILISTIC, AND DATA-DRIVEN APPROACHES

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ABSTRACT

District Heating (DH) systems have been an essential component of urban energy infrastructure for nearly a century, particularly in regions with severe winter climates, such as Northern Europe and the Baltic states. These networks silently and reliably deliver thermal energy to residential, institutional, and industrial consumers. Like all infrastructure systems, the operational lifespan of DH pipelines is finite, largely determined by material properties and installation quality. To ensure long-term serviceability, investment planning, and effective asset management, it is critical to understand the ageing mechanisms of DH pipelines and to develop robust models for service life prediction. The European standard (EN 253, 2024) provides quality assurance guidelines and minimum performance thresholds—typically a 30-year minimum service life under specified operating conditions—for pre-insulated bonded pipe systems. While such standards offer valuable product-level benchmarks, they fall short of providing reliable tools for infrastructure-wide lifetime prediction. Existing modelling approaches for ageing prediction can be broadly categorized into deterministic models (Kim and Kim, 2017; Zan et al., 2020), probabilistic models (Dimoulkas and Amelin, 2017; Yang and Li, 2023) based on failure event statistics, and material science-based models. (Weidlich and Schuchardt (neé Bestrzynski), 2017)classified these respectively as "Top-Down" (statistical) and "Bottom-Up" (material-based) approaches. More recently, the emergence of machine learning and the growing availability of operational and failure data have enabled the development of advanced data-driven models that provide improved predictive capabilities (Hay et al., 2022; Lu et al., 2023).

This paper presents a critical review and updated classification of ageing models for DH pipelines, organizing them into three main categories: deterministic, probabilistic, and data-driven approaches (see Fig. 1). The advantages and limitations of each class are discussed, with an emphasis on their applicability to real-world DH network management. The proposed framework aims to support the development of integrated, hybrid models that can better capture the complex, multi-factorial ageing processes in DH systems.

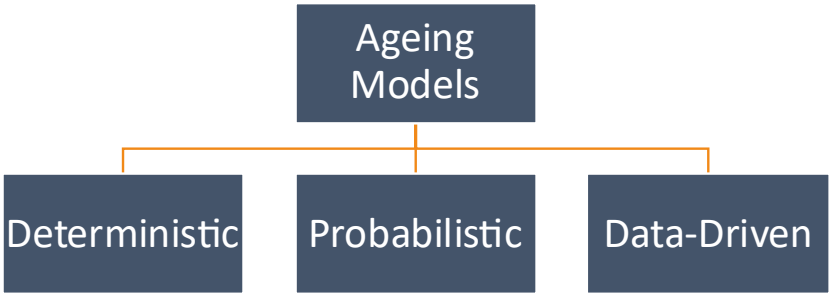


Fig. 1: Classification of ageing models for district heating pipelines.

REFERENCES

Dimoulkas, I., Amelin, M., 2017. Monte Carlo simulation of district heating system short-term operation in electricity markets. energetika 63. https://doi.org/10.6001/energetika.v63i3.3560

EN 253, 2024. Preinsulated Bonded Pipe Systems for Underground Hot Water Networks - Pipe Assembly of Steel Service Pipes, Polyurethane Thermal Insulation and Outer Casing of High Density Polyethylene (Standard No. EN 253). European Committee for Standardization (CEN), Brussels, Belgium.

Hay, S., Huther, H., Sercan-Çalışmaz, K., Weidlich, I., Pourbozorgi Langroudi, P., Kropp, I., Kästner, A. (Eds.), 2022. EnEff:Wärme - Entwicklung von neuen und verbesserten Instandhaltungsstrategien für kleine und große Wärmeverteilnetze durch Kombination statistischer Alterungsmodelle mit materialbasierten Nutzungsdauermodellen: Instandhaltung-FW, Forschung und Entwicklung / AGFW, Der Energieeffizienzverband für Wärme, Kälte und KWK. AGFW Projektgesellschaft für Rationalisierung Information und Standardisierung mbH, Frankfurt am Main.

Kim, Y.-S., Kim, J.-G., 2017. Corrosion Behavior of Pipeline Carbon Steel under Different Iron Oxide Deposits in the District Heating System. Metals 7, 182. https://doi.org/10.3390/met7050182

Lu, S., Gao, Z., Sun, Y., Zhang, S., Li, B., Hao, C., Xu, Y., Gu, W., 2023. Aggregate Model of District Heating Network for Integrated Energy Dispatch: A Physically Informed Data-Driven Approach. https://doi.org/10.48550/ARXIV.2308.10483

Weidlich, I., Schuchardt (neé Bestrzynski), G.K., 2017. New Approach for Asset Management in District Heating (DH) Networks. Energy Procedia 113, 22–27. https://doi.org/10.1016/j.egypro.2017.04.007

Yang, C., Li, Z., 2023. Distributed Conditional-Distributionally robust coordination for an electrical power and flexibility-enhanced district heating system. Applied Energy 347, 121491. https://doi.org/10.1016/j.apenergy.2023.121491

Zan, Z., Song, C., Jing, S., Zhang, J., Lei, Y., Wang, F., 2020. Thermal Fatigue Analysis of the Secondary Network of District Heating Systems in China. J. Pipeline Syst. Eng. Pract. 11, 04020028. https://doi.org/10.1061/(ASCE)PS.1949-1204.0000472

CONFERENCE TOPIC

Future District Heating and Cooling Solutions

PERFORMANCE OF A FORECAST-BASED PREDICTIVE CONTROLLER IN A RESIDENTIAL BUILDING

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SUMMARY

The decarbonization of the heating and cooling infrastructure of residential buildings, especially in cities, is a major challenge to combat climate change. One way to distribute heat and cooling flows efficiently is to use a prediction-based control system. This work examines the behavior of prediction-based control systems in practical applications. Using weather forecast data and a building model, these systems can provide temperature comfort optimized heating and cooling by reacting to external factors that impact the energy production or comfort parameters. This work gives an overview over the concepts at the beginning. After the theoretical approach, the performance in practical operation is analysed. From this, conclusions for future work and improvements of the concept are derived.

INTRODUCTION

The decarbonization of the building sector is an important milestone for Austria in order to achieve its climate targets for 2030 and 2050 (Bundesministerium für Nachhaltigkeit und Tourismus, 2019). Thermal component activation is an important basis for sustainable and climate-friendly new buildings. It enables heating energy to be transferred over a large area to the respective residential units at a low flow temperature. This system turns the activated building mass into a large heat storage unit that can absorb and release a large amount of heat energy without causing significant fluctuations in the temperature of the concrete core. Based on this system, a controller has been developed that is capable of recording environmental influences such as solar radiation for a period in the future and, based on this forecast, controlling the heat input into the component activation in such a way that the desired target temperature is not significantly exceeded or undershot. For example, solar radiation is actively used to maintain the temperature. Additional functions, such as the inclusion of peak wind power, can be integrated into the forecast-based control (MPC) through extensions and boundary conditions.

CONCEPT

Model predictive control (MPC) consists of several parts that interact with each other. Figure 1 shows the schematic structure of MPC:

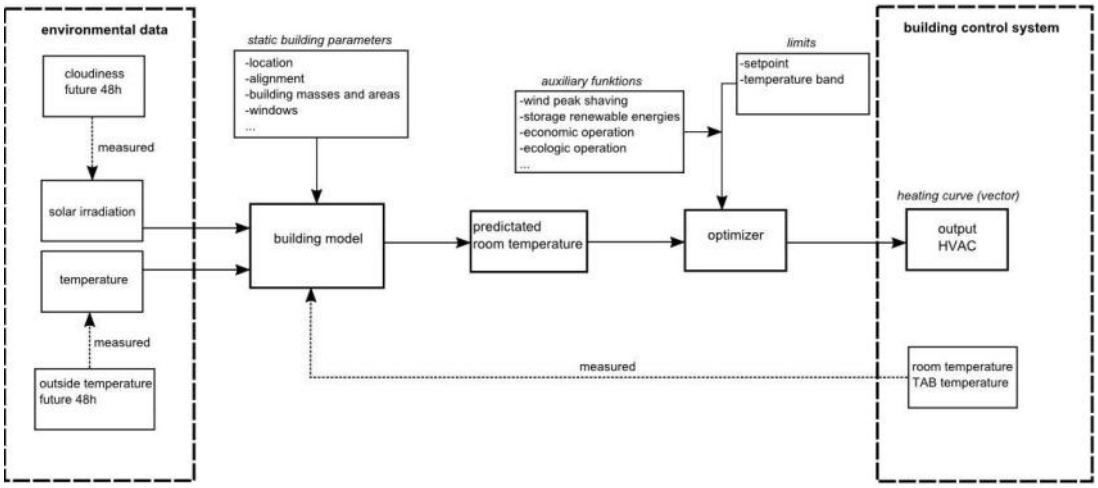


Fig. 1: Schematic diagram of the MPC controller

The first part queries environmental data. To do this, it queries a web service for the local cloud cover and outside temperature for the next 48 hours. The cloud cover can be used to calculate solar radiation depending on the location, time of day, and season (Quaschning, 2011). This information is fed into a building model as external influencing factors. The building model contains the most important parameters that quantitatively describe the building, such as geographical location, orientation, building mass, thermally activated surfaces, and window areas. This model, with its clearly defined system boundaries, is used to calculate the energy balance, taking into account the external influencing factors of outside temperature and solar radiation.
Measurements of the current room temperature and the temperature of the thermally activated ceiling (TAB) are also incorporated into the building model. This building model is used to calculate a predictive room temperature vector for the next 48 hours based on the energy balance. The task of the optimizer, which is the next step, is to compare this predictive room temperature with the target room temperature set by the user and to specify a heating or cooling load for the heating system. In the basic version of MPC, the deviation from the comfort optimum (user setpoint temperature) is determined by minimizing the sum of squared errors.

REFERENCES

Bundesministerium für Nachhaltigkeit und Tourismus (2019) 'Integrierter nationaler Energie- und Klimaplan für Österreich', *Report*, (663).
Quaschning, V. (2011) *Regenerative Energiesysteme*. 7th edn. München: Hanser Verlag.

CONFERENCE TOPIC

Digitalization for Smart, Resilient Energy Systems, Building the Future: Smart Energy Infrastructure for the Energy Transition, Flexibility and Stability in Thermal and Electric Grids, Next-Generation Technologies for Renewable Energy and Resource Efficiency

AN APPROACH FOR A DISCURSIVE TRANSFORMATION OF ENERGY SYSTEMS USING AGGREGATED BUILDING MODELS

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SUMMARY

The Stuttgart Research Initiative for the Discursive Transformation of Energy Systems (SRI DiTEnS) addresses socio-technical challenges related to the transformation of our energy system towards climate neutrality. The initiative develops dialogue-based planning processes integrating heterogeneous stakeholder participation and using visualization methods and energy simulation models. A series of workshops enables stakeholders to develop shared knowledge and reach consensus on transformation measures for heating, cooling, and electricity supply systems. One key research focus in this context is developing scalable aggregated building models for the automatic generation of demand profiles for heating, cooling and electricity using limited but open data. These models enable high-resolution spatial and temporal analyses from small district to city scales, providing the analytical foundation for evaluating transformation measures such as refurbishment strategies. Data availability and preprocessing are central modeling challenges, which will be addressed in this article.

Keywords: transformation of energy systems, dialogue, heterogeneous stakeholders, aggregated building models, data preprocessing

INTRODUCTION

A far-reaching transformation of our energy system, i. e. the heating, cooling and electricity supply, is necessary in order to achieve the federal state, national and European climate targets. In addition to the technical complexity and diversity of future energy systems, this transformation process is particularly challenging due to social frictions, conflicts, and the involvement of a broad range of heterogeneous stakeholders.

To address these challenges and support the successful implementation of the energy transition, the Stuttgart Research Initiative for the Discursive Transformation of Energy Systems (SRI DiTEnS) [1] is establishing a new inter- and transdisciplinary research network. The initiative's initial research project is entitled “VR-based simulative design of a social dialogue on the transformation of urban energy systems”.

To implement this initial research project, five institutional partners from the University of Stuttgart are collaborating. The energy technology and economic aspects are addressed by the Institute of Building Energetics, Thermotechnology and Energy Storage (**IGTE**), the Institute of Energy Economics and Rational Energy Use (**IER**), and the Institute of Power Transmission and High Voltage Technology (**IEH**). The information technology aspects, such as visualization by means of virtual reality (VR) or augmented reality (AR), are implemented by the High Performance Computing Center Stuttgart (**HLRS**). The Center for Interdisciplinary Risk and Innovation Studies (**ZIRIUS**) is responsible for developing and facilitating the social science and discursive dimensions of the project.

A DISCURSIVE TRANSFORMATION OF ENERGY SYSTEMS

One focus of the project is exploring different dialogue formats using at least three case studies. These case studies shall vary not only in the composition and expertise of the stakeholder groups but also in the methods of evaluation analysis, narrative structure, and the specific objectives of each workshop in an interlinked, sequential workshop series. Additionally, the case studies shall vary in their composition of technical aspects, including the existing infrastructure such as district heating networks, the state of refurbishment of the buildings and the urban structure, i. e. the building typology and usage.

The overarching aim of the dialogue processes, structured as a series of workshops, is to support stakeholders in reaching informed decisions and in implementing concrete consensus-based measures to transform the local energy systems towards climate neutrality. The initial phase of these workshops focuses on developing a shared knowledge base and fostering mutual understanding among the stakeholders. In subsequent workshop formats, the aim is to identify the parameters and results most relevant to stakeholders' decision-making. The dialogue processes are underpinned by a toolbox of simulation models, including the following described aggregated building models, which enable stock and potential analyses, similar to municipal heat planning, but address the combined heating, cooling, and electricity demands and supply. With the toolbox of simulations different variants of energy supply systems are simulated, guided by parameters defined through the dialogue process. As a result of the dialogue process, stakeholder-specific questions are answered, stakeholder-preferred variants can be identified, and concrete measures are derived. Thus, the basis for achieving consensus on the further implementation of the measures is provided.

AGGREGATED BUILDING MODELS

For a stock and potential analyses, it is in principle possible to calculate the heating, cooling, and electricity demand of all buildings in a case study site at any given time using detailed dynamic simulations. Such detailed simulations would, for example, be necessary to adequately account for capacitive effects of the building mass. However, this approach faces practical limitations, for instance, during interactive stakeholder workshops due to constrained computational time. Additionally, the input data required to simulate the thermal behavior of individual buildings are often unavailable or prohibitively expensive to obtain. Therefore, individual thermal simulations of each building across an entire case study site are not feasible under these conditions.

At the Institute of Building Energetics, Thermotechnology and Energy Storage (IGTE), one key focus in the initial research project is therefore the development of aggregated building models to simulate the thermal behavior of buildings. These models are intended to enable the automated generation of heating, cooling, and electricity demand profiles for both existing and new buildings. The envisioned models are designed to be scalable, from small districts with only a few buildings to entire cities. The aim of developing aggregated building models is to create models that produce sufficiently accurate and meaningful results using limited input data while ensuring acceptable computing times for all scales, comparable to [2] and [3]. A central aim of the modeling approach is to incorporate key influencing factors such as the state of refurbishment of buildings and aggregated occupancy and usage patterns. The aggregated building models should support high-resolution temporal and spatial analyses. These analyses will be used to examine current and future demand and supply structures, including strategies for refurbishment and the integration of renewable energy sources.

One of the main challenges in developing the aggregated building models lies in acquiring and preprocessing the required input and validation data [4]. Input data includes, for instance, thermal properties of the building envelope

and energy supply system characteristics. Validation data consists, for example, of measured energy consumption profiles. The validity of aggregated building model results will depend significantly on the quality of the input and validation data. To ensure applicability across different case study sites, the aggregated building models are being designed to rely on open data and on data that is largely accessible through automated processes. Priority is given to datasets that include metadata on data quality and update status. In addition, the data model architecture is planned to be modular and expandable. This will allow for the integration of more detailed data provided by stakeholders before or during the dialogue processes described above.

This article therefore presents the general modeling and validation concept for aggregated building models developed in the initiative's initial research project. It outlines the challenges of data availability and describes methods for preprocessing input data for use in aggregated building models.

REFERENCES

[1] https://www.ditens.de, retrieved on 07.04.2025

[2] Johari, F. et al., (2023), Urban building energy modeling from geo-referenced energy performance certificate data: Development, calibration, and validation. Sustainable Cities and Society 96 (Elsevier Ltd.).

[3] Issermann, M. et al., (2021), Interactive urban building energy modelling with functional mockup interface of a local residential building stock. Journal of Cleaner Production 289 (Elsevier Ltd.).

[4] Wang, C. et al., (2022), Data Acquisition for Urban Building Energy Modeling: A Review. Building and Environment 217 (Elsevier Ltd.).

CONFERENCE TOPIC

Transform Cities: Holistic Approaches to Sustainable Urban Energy

ACKNOWLEDGEMENTS

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- Institute of Energy Economics and Rational Energy Use (IER)
- Institute of Building Energetics, Thermotechnology and Energy Storage (IGTE)
- Institute of Power Transmission and High Voltage Technology (IEH)
- High Performance Computing Center Stuttgart (HLRS)
- Center for Interdisciplinary Risk and Innovation Studies (ZIRIUS)

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EFFECTS OF HEAT SAVING MEASURES ON THERMAL COMFORT IN AN OFFICE BUILDING IN GERMANY

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SUMMARY

This paper presents results from a real-world laboratory which was set up in a university office building to explore how smart technologies and non-technical interventions can enable more sustainable operation of public non-residential buildings. Various heating control strategies and non-technical interventions, so called “treatments”, were tested as part of experiments during the 2023/2024 and 2024/2025 heating seasons. The treatments included e. g. presence-based heating control and variations in the heating system’s flow temperature. The user perception of temperatures and comfort was assessed via surveys. The focus of this paper is to evaluate the impact of the treatments on user comfort perception and heat consumption, using i. e. linear regression. The results are intended to support future experiments and interdisciplinary research in smart control strategies.
Keywords: smart technologies, real-world laboratory, sustainable building operation, user comfort, user survey

GENERAL SETUP OF THE EXPERIMENTS AND THE SURVEYS

The definition of user comfort has broadened significantly over recent decades, now encompassing a wide array of physical, technical, social, and societal dimensions [Gossauer, 2008a], with thermal comfort remaining a central focus of research within this broader framework. Established determinants of thermal comfort include e. g. air temperature, mean radiant temperature, relative humidity, air velocity, clothing insulation, and metabolic rate [DIN EN ISO 7730, 2006]. Research focused on user behavior in buildings has predominantly addressed heating practices, examining technical and sociodemographic determinants, user attitudes, and the effects of interventions such as energy feedback mechanisms [BFEWB, 2024]. Key findings in the literature indicate that users do not always take advantage of available control options, and that sociodemographic characteristics and the provision of information can significantly influence behavior [BFEWB, 2024].
Contributing to research on climate-neutral buildings, a real-world laboratory was set up to investigate the interaction between user-perceived thermal comfort and energy-saving measures under real conditions. This was implemented by performing a variety of treatments, including control strategies and non-technical interventions, in an office building built in 1989 with about 50 building users located in Stuttgart, Germany. Starting operation in November 2023, the treatments were implemented on the first and second floor while continuing operation as usual on the third and highest floor as a reference. In the heating season of winter 2023/2024, treatments included: presence-based heating control, a heat-up period, and giving feedback about possibilities to reduce the energy demand. The experiment was repeated during the heating season 2024/2025 with treatments including varying heat-up periods per floor, and modifying the heating system's flow temperature for the whole building.

In each room, sensors logged air temperature, relative humidity, illumination, and motion. In addition, the system logged the temperature set by the user(s) of the room (setpoint temperature) and the system's target temperature (operating temperature). The radiators were equipped with smart thermostatic valves. Per building level, a heat meter measures the thermal energy consumption data such as heating power, water flow rate, supply and return temperature. Data was recorded at a five-minute interval.
During the treatments, a survey was conducted to assess the perceived user comfort. The survey of the first heating season comprised six closed questions concerning e. g. the perception of room temperature, personal productivity, clothing, brightness, and air velocity. A revised survey, deployed in 2024/2025, aimed to improve clarity, reduce fatigue, and increase response rate. It included three closed and one open question on the perception of room temperature, general comfort, and outside weather. In addition, at the launch of the first survey in each heating season, demographic information was collected, including year of birth and gender. In the heating season 2024/2025, participants were also asked to indicate their general temperature preference for work environments i.e., whether they typically prefer warmer or cooler rooms. This paper presents the results of this survey in context of the treatments in order to investigate if and how specific control strategies affect the measurable comfort parameters, the corresponding user comfort perception, and heat consumption.

PRELIMINARY RESULTS AND FOCUS OF THE STUDY

The first in-depth analysis showed that, by means of control strategies, up to 40 % of heating energy can be saved in comparison across treatment phases of the second experiment in 2024/2025 [Ullmann et al, 2025]. Further energetic evaluations are to follow. In addition, potential negative effects of these savings on user comfort need to be taken into account. To investigate how different treatments affect heat consumption, linear regression models are employed to analyse the relationship between perceived comfort, user behavior, and physical environmental conditions. As independent variables, e. g. self-reported temperature preferences, gender, age, and selected survey items will be considered to get a better insight into driving factors of user comfort.
Another key question addressed in this paper concerns the variation in thermal comfort ratings, as preliminary findings indicate a notable degree of intra-individual inconsistency in thermal comfort ratings. Identical temperatures may be perceived as more or less comfortable by the same individual depending on the time of day or other factors. In addition, the temperature range in which the room temperature is rated as good or comfortable seems to be highly variable. These patterns will be further analysed to identify underlying drivers of variability.
Finally, the results are compared to existing studies within the broader field of thermal comfort research. The implications for energy-efficient heating strategies in non-residential buildings are discussed, with particular attention to how comfort perception can inform control systems. Additionally, the findings will influence the design of the upcoming experiment in the 2025/2026 heating season.

REFERENCES

[Ullmann et al, 2025] Ullmann, J.; Helf, R.; Lierhammer, P.; Häbig, P.; Eltrop, L.; Leger, M.; Drück, H., Hufendiek, K. (2025), Ergebnisse des Einsatzes intelligenter Technologien zur Verringerung des Wärmeverbrauchs eines Bürogebäudes. Tagungsband Symposium Zukunft Wärme, 20.-22. Mai 2025, Bad Staffelstein, Germany, p. 361-377.
[BFEWB, 2024] Begleitforschung Energiewendebauen, (2024), Nutzendenverhalten – Einflussfaktoren und Einflussnahme auf die Gebäudeenergieperformance, Querauswertung der Projekte der Förderinitiative Energiebauwende, Wissenschaftliche Begleitforschung Energiewendebauen, Modul 2.
[DIN EN ISO 7730, 2006] Deutsches Institut für Normung, (2006), DIN EN ISO 7730: Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. Berlin, Germany: Beuth Verlag.

[Gossauer, 2008] Gossauer, E. (2008a), Nutzerzufriedenheit in Bürogebäuden - Eine Feldstudie. Dissertation, Universität Karlsruhe, Germany

CONFERENCE TOPIC

Digitalization for Smart, Resilient Energy Systems

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BIO-BASED ALTERNATIVES TO GLASS FIBERS: SYSTEMATIC LIFE CYCLE ASSESSMENT REVIEW AND PROSPECTIVE GLOBAL WARMING POTENTIAL ANALYSIS

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SUMMARY

This study reviews life cycle assessments (LCAs) that examine the substitution of glass fibers with bio-based alternatives. It also presents a prospective analysis of global warming potential (GWP) using the PREMISE tool across different socio-techno-economic scenarios. Bio-based fibers such as flax and cellulose show significantly lower GWP compared to glass fibers, yet fully bio-based composites made from wood-derived fibers remain largely overlooked in reviewed LCA studies. This gap highlights the need for more comprehensive cradle-to-grave LCAs comparing wood-derived composites with glass fiber reinforced polymers (GFRP), particularly for applications in renewable energy production like wind turbine blades.

Key words: life cycle assessment, glass fibers, bio-based fibers, bio-composites

INTRODUCTION

The wind energy sector in the European Union is rapidly expanding under the Renewable Energy Directive and seeking sustainable alternatives to conventional materials, particularly energy intensive GFRPs, for turbine blade production (European Parliament and Council, 2023). Over the past two decades, interest in bio-based fiber composites—such as flax, hemp, and cellulose—has grown as sustainable lower-carbon alternatives to traditional glass fibers (John and Thomas, 2008; Hammad et al., 2022). However, their environmental impact over the full life cycle remains unclear and depends on factors such as fiber processing, resin choice, and application. Therefore, prospective LCA studies are needed to evaluate these impacts across all stages, from cradle to grave, and to account for uncertainties in early-stage production. LCA is a standardized method for environmental performance evaluation of the product from raw material extraction phase until the end of life (Guinée et al., 2016). To identify the state of the art and research gap, this work aims to: (1) systematically review LCA studies on substituting glass fibers with bio-based fibers in composites, highlighting methodological trends and key impact categories; and (2) estimate the prospective GWP of flax, cellulose, and glass fibers in 2050 using the PREMISE tool under different shared socioeconomic pathway (SSP) scenarios.

METHODOLOGY

To identify relevant LCA studies, structured literature search based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses' (PRISMA) methodology was conducted using Scopus database with the key words: bio fiber OR cellulose fiber AND glass fiber AND LCA OR life cycle assessment (Page, 2021). A search of articles published after August 2015 yielded 60 results. After abstract screening, 25 articles were pre-screened, of which 15 were included in the analysis following the detailed review of the methods and conclusions sections. To estimate GWP, the PREMISE (v2.2.0) Python library was used to project background data from the REMIND integrated assessment model (Baumstark et al., 2021; Sacchi et al., 2022). The functional unit was defined based on mechanical properties—specifically, tensile modulus—as in Hervy et al. (2015), with 1 kg of glass fiber (specific modulus: 28 GPa cm^3 g^{-1}) used as the reference. Inventory data were sourced from ecoinvent 3.8 and implemented in the Brightway LCA framework, applying the IPCC 2013 GWP100a method (Wernet et al., 2016). Scenarios included BASE (based on last availability ecoinvent data v 3.11), SSP1 (sustainable development), SSP2 (middle-of-the-road), and SSP5 (fossil-fueled growth), allowing for comparison of projected emissions trajectories.

RESULTS AND DISCUSSION

Findings of the literature review reveal that automotive, aircraft, and construction industries each account for about 27% of applications, with emerging uses in wind and tidal turbine blades at around 13% of all the papers reviewed. Flax is the most studied fiber (40%), followed by other bio-fibers (33%) and wood-derived fibers (27%), which remain underexplored despite their potential as GFRP substitutes (Oliver-Ortega et al., 2019). Among these studies, 60% used glass fiber composites as a reference material, 13% used carbon fiber composites, and the remaining studies did not include a reference material. Most LCAs use cradle-to-grave boundaries (53%), with 47% using cradle-to-gate. SimaPro and openLCA are the most common LCA tools, each used in 33% of studies.

Flax and hemp-fiber-based composites reduce environmental emissions compared to GFRP (Gkoloni et al., 2021; Lopez-Arraiza et al., 2025), but the resin required to improve durability is largely fossil-based and energy-intensive, which can offset the environmental gains of the bio-based fibers (Corona et al., 2015). Despite the usage of bio-resin matrix with wood-derived fibers, it was found that total GWP was slightly higher than GFRP as the manufacturing of the bio-resins and processing of fibers are energy intensive as well (Oliver-Ortega et al., 2019). Similarly, Liu et al., (2024) found that cellulose acetate/miscanthus composites had a higher GWP of 8.31 kg CO_2-eq/kg compared to 2.46 kg CO_2-eq/kg for GFRPs, mainly due to the energy-intensive fibrillation process. Unlike well-established and optimized GFRP production (Martynova et al., 2018), these bio-based composites are still at an early technology readiness level. Their GWP is expected to decrease over time through the learning effect, as initially slow and inefficient processes become more efficient and cost-effective (Thomassen et al., 2020).

Applying the PREMISE tool on GWP of cellulose fibers, shows a comparatively modest reduction in GWP over time (SSP scenarios in regard to year 2050), whereas glass fibers achieve the largest absolute decrease across all SSP scenarios (Figure 1). Nevertheless, cellulose fibers maintain a consistently low GWP in every scenario—lower than flax fibers—representing around 25% of glass fiber GWP in both BASE and SSP1 scenarios. Despite their smaller relative improvement, cellulose fibers have a favorable low emissions baseline compared to flax and glass fibers. Even with the largest relative reductions in SSP1 and SSP2, glass fibers do not achieve the current performance of flax and remain higher than cellulose. This creates a feedback loop: the higher demand for renewable energy infrastructure in SSP1 and SSP2 such as wind turbines, could increase the demand for fiber production, which in turn consumes more energy. This highlights the importance of developing sustainable composites for wind turbine applications to support sustainable expansion of renewable energy.

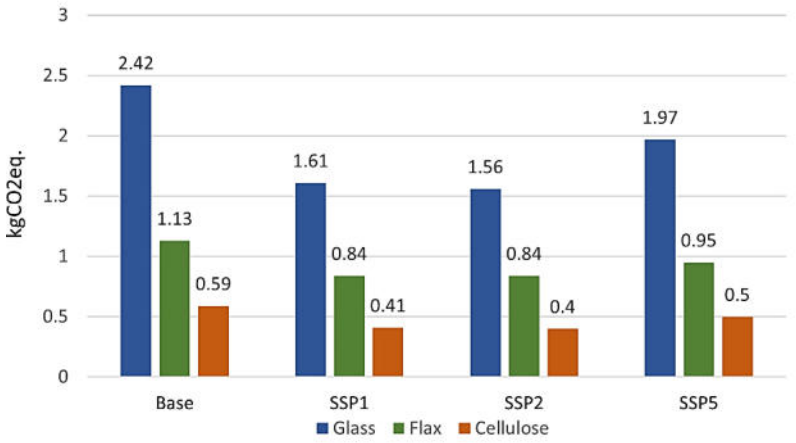


Figure 1. GWP estimation of fiber options under various SSP scenarios.

To conclude, our review found a clear gap in LCAs of fully bio-based composites, with only one study on cellulose fiber–bio-resin systems. The main drivers of GWP are the energy-intensive fiber processing and the type and amount of resin needed to match GFRP properties. Future research should focus on prospective LCAs of innovative emerging materials such as densified delignified wood (Frey et al., 2018). PREMISE-based GWP estimations show that cellulose fibers consistently have the lowest impact, highlighting their potential for wind turbine applications. As renewable energy expands, so does the demand for wind turbines and the fibers required to make them, increasing energy use and associated emissions. Therefore, reducing the environmental impact of fiber production is key to ensure that renewable energy expansion will have a net climate benefit.

REFERENCES

Baumstark, L., et al., 2021. REMIND2.1: transformation and innovation dynamics of the energy-economic system within climate and sustainability limits. Geoscientific Model Development, 14(10), pp.6571-6603. https://doi.org/10.5194/gmd-14-6571-2021
Corona, A., et al., 2015. Comparative environmental sustainability assessment of bio-based fiber reinforcement materials for wind turbine blades. Wind Engineering, 39(1), pp.53-63. https://doi.org/10.1260/0309-524X.39.1.53
European Parliament and Council, 2023. Directive (EU) 2023/2413 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources. Official Journal of the European Union.
Frey, M., Widern, D., Segmehl, J., Casdorff, K., Keplinger, T. & Burgert, I., 2018. Delignified and densified cellulose bulk materials with excellent tensile properties for sustainable engineering. ACS Applied Materials & Interfaces. https://doi.org/10.1021/acsami.8b03208
Gkoloni, N. & Kostopoulos, V., 2021. Life cycle assessment of bio-composite laminates: a comparative study. IOP Conference Series: Earth and Environmental Science, 899(1), p.012041. https://doi.org/10.1088/1755-1315/899/1/012041
Guinée, J.B., et al., 2016. Life cycle assessment: past, present, and future. Environmental Science & Technology, 50(1), pp.28–38. https://doi.org/10.1021/acs.est.5b03576
Hammad, M., et al., 2022. Life cycle assessment of natural fibers: current practices and future prospects. Journal of Cleaner Production, 345, p.131096. https://doi.org/10.1016/j.jclepro.2022.131096
Hervy, M., et al., 2015. Life cycle assessment of nanocellulose-reinforced advanced fiber composites. Composites Science and Technology, 118, pp.154-162. https://doi.org/10.1016/j.compscitech.2015.08.024
John, M. & Thomas, S., 2008. Biofibers and biocomposites. Carbohydrate Polymers, 71(3), pp.343-364. https://doi.org/10.1016/j.carbpol.2007.05.040
Liu, Y., et al., 2024. A comparative life cycle assessment of a new cellulose-based composite and glass fiber reinforced composites. Journal of Polymers and the Environment, 32(5), pp.2207-2220. https://doi.org/10.1007/s10924-023-03059-7
Lopez-Arraiza, A., et al., 2025. Life cycle assessment of glass fiber versus flax fiber reinforced composite ship hulls. Scientific Reports, 15(1), p.16283. https://doi.org/10.1038/s41598-025-00811-y
Martynova, E. & Cebulla, H., 2018. Glass fibers. In: Inorganic and Composite Fibers. 1st ed. Amsterdam: Elsevier, pp.131-163.
Oliver-Ortega, H., et al., 2019. Research on the use of lignocellulosic fibers reinforced bio-polyamide 11 with composites for automotive parts: car door handle case study. Journal of Cleaner Production, 226, pp.64-73. https://doi.org/10.1016/j.jclepro.2019.04.047
Page, M.J., et al., 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ, 372, p.n71. https://doi.org/10.1136/bmj.n71
Sacchi, R., et al., 2022. PRospective EnvironMental Impact asSEment (Premise): a streamlined approach to producing databases for prospective life cycle assessment using integrated assessment models. Renewable and Sustainable Energy Reviews, 160, p.112311. https://doi.org/10.1016/j.rser.2022.112311
Thomassen, G., et al., 2020. A review on learning effects in prospective technology assessment. Renewable and Sustainable Energy Reviews, 130, p.109937. https://doi.org/10.1016/j.rser.2020.109937
Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E. & Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. International Journal of Life Cycle Assessment, 21(9), pp.1218-1230. https://doi.org/10.1007/s11367-016-1087-8

CONFERENCE TOPIC

Life Cycle Assessment, Circular Economy Strategies for the Energy Transition

COMPATIBILITY OF STEEL SLAG WITH LEAD AT 750°C FOR APPLICATION IN THERMAL ENERGY STORAGE SYSTEMS

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SUMMARY

This study analyses the applicability of steel slag in packed-bed thermal energy storage (TES) systems with liquid lead as heat transfer fluid. The compatibility of slags from electric arc furnace (EAF) and basic oxygen furnace (BOF) with lead was analyzed after being in contact with the liquid metal at 750°C for 1000 h with the result that slag with lower iron and magnesium content performs better.
Keywords: packed bed, liquid metal, steel slag, thermal energy storage

INTRODUCTION

Sensible TES have been proposed as viable solution for waste heat recovery in energy-intensive industries, such as steel manufacturing, where exhaust temperatures can reach up to 1200°C [1]. For high-temperature applications there are only a few usable heat transfer fluids (HTFs). At the Karlsruhe Liquid Metal Laboratory, liquid metals are investigated as HTF due to their high thermal conductivity and large temperature range, in which they are liquid. A laboratory-scale packed-bed TES using lead bismuth eutectic (LBE) as HTF has been tested with success [2]. However, the use of LBE and zirconium silicate packed-beds represents high capital costs. A step to a more cost-efficient concept involves lead as HTF and waste material as filler material. For this reason, steel slag's compatibility with lead is being investigated in this study.

EXPERIMENTAL PROCEDURES

EAF and BOF slags with varying compositions were acquired from the steel producers thyssenkrupp MillServices & Systems (EAF1 and BOF1) and Fondium Singen GmbH (EAF2). The composition of the studied slags can be found in Table 1.

Table 1: Composition of the analysed slags in wt%

Element	O	Na	Mg	Al	Si	S	P	Ca	Ti	Cr	Mn	Fe
BOF1	38	-	1.1	0.7	11.0	-	1	32.8	<1	-	1.6	16.9
EAF1	40	-	7.7	4.5	7.8	-	-	18.4	0.4	<1	4.6	20.6
EAF2	49.0	0.5	1.0	5.1	22.3	0.4	-	20.4	0.2	<1	0.4	0.5

Static exposure was performed in lead at 750°C for 1000 h. Crucibles containing lead and the material samples were placed in a furnace with a quartz tube as test chamber under a reducing atmosphere, procedure described in detail by Zehnder et al. [3]. During the test, only a minor Ar5%H_2 gas flow was selected to reflect the conditions of the TES, where only trace amounts of oxygen are expected to be present in the packed-bed. The samples were analysed before and after exposure using scanning electron microscopy (SEM). Elements were determined using energy-dispersive spectroscopy (EDS) and the crystal structure of each sample was analysed using X-ray diffraction (XRD).

RESULTS

In a first test run, EAF1 and BOF1 were exposed. After exposure, microcracks were observed in both samples, with BOF1 showing a higher density of cracks compared to EAF1. The cracks primarily occurred in the bredigite ($Ca_{14}Mg_2(SiO_4)_8$) phase of EAF1 and the (Ca,Si)O and Fe-Mg oxide phases of BOF1. This is most likely due to thermal alteration of the tested materials, leading to phase transformation accompanied by volume changes (Fig. 1a,b) [3]. Additionally, both materials exhibited liquid lead attacks in the Fe-Mg oxide phases due to dissolution during contact with the liquid lead (Fig. 1a) [3]. The studied samples on Fig. 1c-e.

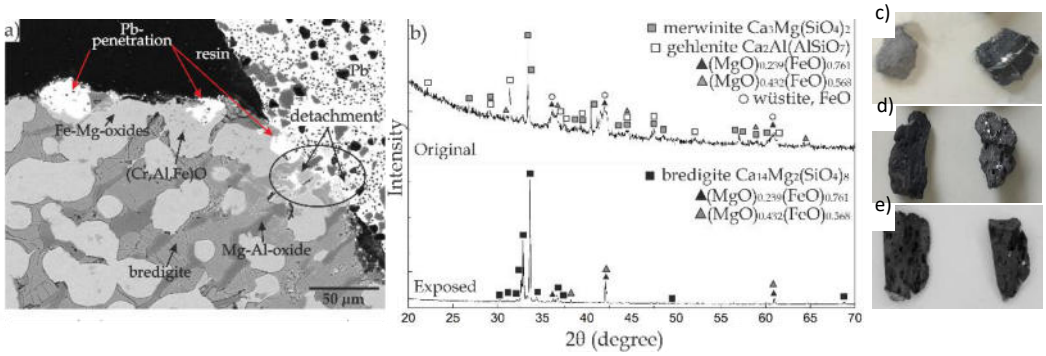


FIG. 1: A) CROSS-SECTION OF THE EAF1 SAMPLE AFTER EXPOSURE IN LEAD AT 750°C AND B) ASSOCIATED XRD PATTERN BEFORE AND AFTER EXPOSURE (ADAPTED FROM [3]); PICTURES OF THE STUDIED SAMPLES BEFORE AND AFTER EXPOSURE: C) BOF1 AND D) EAF1 [3]; E) EAF2

Since the attacks primarily occurred in the Fe-Mg oxide phases, a slag with lower Fe and Mg content (EAF2) was expected to perform better, so it was tested in the second run. After exposure, EAF2 showed only a small amount of lead attached to the surface (Fig. 1e), which serves as the first indication of a low interaction with the liquid lead. This was further confirmed in the cross section. Additionally, no cracks were observed; however similar to the other samples a thermal alteration happened leading to phase transformation in the matrix.
The analyses of all studied slags will be shown as well as a comparison between the different types of slag.

SUMMARY AND CONCLUSION

Three different slags were exposed. Both EAF1 and BOF1 exhibited microcracks due to thermal alteration and contained Fe-Mg oxide phases, which were slightly attacked by the liquid lead. Learnings from this prior analysis resulted in the choice for a more suitable slag. After preliminary observations EAF2 showed promising results indicating better compatibility with the liquid metals compared to the previous slags, but more research is needed to confirm its suitability as TES material. Cyclic thermal test as well as mechanical test are to be performed.

REFERENCES

[1] Ortega-Fernández, I., Calvet, N., Gil, A., Rodríguez-Aseguinolaza, J., Faik, A., & D'Aguanno, B., (2015), Thermophysical characterization of a by-product from the steel industry to be used as a sustainable and low-cost thermal energy storage material. Energy, 89, 601–609.

[2] Müller-Trefzer, F., Niedermeier, K., Daubner, M., & Wetzel, T., (2022). Experimental investigations on the design of a dual-media thermal energy storage with liquid metal. Applied Thermal Engineering, 213, 118619.

[3] Zehnder, M., Purwitasari, A., Heinzel, A., Niedermeier, K., (2025). Study on low-cost storage material for use in high-temperature thermal energy storage with lead as heat transfer fluid. Energy Storage – under revision

CONFERENCE TOPIC

Next-Generation Technologies for Renewable Energy and Resource Efficiency; Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications: Emerging Heat and Cold Storage

DECARBONIZATION OF PROCESS HEAT IN GERMANY: AN OVERVIEW OF EXISTING STUDIES

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SUMMARY

Industrial process heat accounts for around 21% of Germany's final energy demand, making its decarbonization a decisive challenge for meeting national and global climate targets. Numerous studies have addressed the technological and economic pathways toward CO_2-neutral process heat, yet their approaches, system boundaries, and technology focus vary widely. This paper provides a structured overview of key studies on the decarbonization of process heat in Germany, highlighting common findings, methodological gaps, and implications for industry and policy. It points to the lack of consideration of concentrating solar thermal (CST) and the absence of a systematic analysis of thermal energy storage as aspects that should be addressed in future studies.

Keywords: process heat, industrial decarbonization, Germany, electrification, hydrogen, concentrating solar thermal (CST), thermal storage, literature review

ABSTRACT

This work reviews more than 20 studies on the decarbonization of industrial process heat in Germany. The reports provide valuable information on steps toward decarbonization and often include high-quality results and insights. However, they also reveal aspects that need improvement and should be addressed in future studies.

One of the most important findings from the review is the clear prioritization of electrification and hydrogen as the main technologies to replace fossil fuels in industrial process heat in Germany. This prioritization is usually combined with improved efficiency where possible and the use of waste heat. The largest study to date in Germany, carried out by Fraunhofer ISI and RWTH Aachen and funded by the environment agency of the German government [1], points in this direction: electrification and hydrogen show by far the largest technical potential and are expected to be the primary drivers of process-heat decarbonization. Other technologies are relegated to niche applications. Electrification is advantageous at lower temperatures, hydrogen at very high energy densities. Electrification requires a more profound conversion of the plant fleet than hydrogen or synthetic methane. Overall, the technical feasibility of converting the plant fleet by 2045 is given. CO_2-neutral alternatives are available or under development for all applications. The switch to CO_2-neutral technologies is associated with significantly higher energy costs. This prioritization of electrification and hydrogen as core technologies is also reflected in other relevant studies, such as those resulting from the Ariadne Project [2,3,4] or those promoted by Agora Energiewende [5] and Agora Industrie [6], or the study on decarbonization of energy-intensive industries using the example of Gelsenkirchen conducted by Fraunhofer Umsicht and Wuppertal Institut [7].

However, there are other technologies that can also play an important role in the decarbonization of process heat that are barely considered in these studies, such as concentrated solar technology, despite their proven potential for medium-temperature process applications up to 400°C. Some exceptions highlight this untapped potential.

For instance, the 2025 Fraunhofer ISE study [8] on solar process heat demonstrates that solar thermal systems, especially at coverage levels of 20–50%, can achieve cost competitiveness with natural gas under German conditions, with short payback periods (3–8 years) and significant CO_2 reductions. Earlier work from the University of Kassel [9] and subsequent analyses by Krüger et al. [10] confirm the technical feasibility of CST in Central Europe, though these findings have rarely been integrated into broader comparative studies. The omission of solar thermal technologies in otherwise comprehensive reports represents a major gap in the literature, limiting the awareness and uptake of CST by industry stakeholders. It is also important to conduct a systematic analysis of the importance of storage, especially thermal storage, in achieving decarbonization targets. Although its importance as a source of flexibility and cost reduction is generally recognized, it has hardly been addressed systematically in techno-economic analyses in studies to date.

Beyond technology coverage, another challenge lies in the accessibility and usability of results. While extensive system studies provide high scientific value, their scope and complexity make them difficult for companies to apply directly. Studies that are more accessible to industry, do not involve a large number of pages, and have a clear and compact visual representation would help industry understand the technological options available, their advantages and disadvantages, and their costs. Examples include the NRW.4Climate publications [11, 12] and policy briefs [13], which provide concise and industry-oriented guidance.

Study focus also varies widely: some reports analyse decarbonization at regional or sectoral level (e.g., Gelsenkirchen, Hamburg, Lower Saxony) [1,7,14–17], while others present application examples for specific companies and temperature levels [1,18]. In any case, methodological heterogeneity (different assumptions on costs, lifetimes and temperature ranges) complicates cross-study comparisons. Other work focusses on different issues such as reform options for energy and electricity tax relief schemes [19] or on efficiency improvement measures [20].

In response to these findings, the main deficits of existing studies can be summarized as follows: (1) insufficient consideration and lack of neutral comparison of all relevant technology options, in particular concentrating solar thermal (CST) and thermal storage; (2) lack of harmonized cost and performance assumptions, which hinders clear benchmarking; (3) limited availability of compact and visual result formats tailored to industrial decision-makers; and (4) considerable methodological heterogeneity and a lack of company case studies that are transferable to other firms. Future research should therefore broaden technology coverage, provide more comparable methodological frameworks, and deliver results in formats that are accessible and useful for both policy and industry stakeholders.

REFERENCES

[1] Fraunhofer-Institut für System- und Innovationsforschung ISI and Institut für Industrieofenbau und Wärmetechnik (IOB) RWTH Aachen University. (2023). CO2-neutrale Prozesswärmeerzeugung Umbau des industriellen Anlagenparks im Rahmen der Energiewende: Ermittlung des aktuellen SdT und des weiteren Handlungsbedarfs zum Einsatz strombasierter Prozesswärmeanlagen. Commissioned by the German Environment Agency.
[2] Luderer, G.; Kost, C.; Sörgel, D.; et al. (2021). Deutschland auf dem Weg zur Klimaneutralität 2045: Szenarien und Pfade im Modellvergleich. Kopernikus-Projekt Ariadne, Potsdam.
[3] Ueckerdt, F.; Pfluger, B.; Odenweller, A.; et al. (2021). Durchstarten trotz Unsicherheiten: Eckpunkte einer anpassungsfähigen Wasserstoffstrategie. Kopernikus-Projekt Ariadne, Potsdam.
[4] Luderer, G.; Bartels, F.; Brown, T.; et al. (2025). Die Energiewende kosteneffizient gestalten: Szenarien zur Klimaneutralität 2045. Kopernikus-Projekt Ariadne, Potsdam.
[5] Agora Energiewende and Wuppertal Institut. (2019). Klimaneutrale Industrie: Schlüsseltechnologien und Politikoptionen für Stahl, Chemie und Zement. Berlin.

[6] Fraunhofer ISI. (2024). Direct Electrification of Industrial Process Heat. An assessment of technologies, potentials and future prospects for the EU. Commissioned by Agora Industry. Berlin.
[7] Fraunhofer UMSICHT and Wuppertal Institut. (2023). Dekarbonisierung der industriellen Prozesswärme im energieintensiven Mittelstand am Beispiel des Klimahafens Gelsenkirchen als klimaneutraler Industrie- und Logistikstandort.
[8] Fraunhofer-Institut für Solare Energiesysteme ISE and Bundesverband Solarwirtschaft e. V. (BSW-Solar). (2025). Solare Prozesswärme für die deutsche Industrie – Ertrag und Wirtschaftlichkeit im Vergleich zu konventioneller Wärmeversorgung. Freiburg and Berlin.
[9] Uni Kassel. (2011). Das Potential solarer Prozesswärme in Deutschland. Kassel.
[10] Krüger, D.; Fischer, S., Nitz, P.; Inigo Labairu, J. (2021). Chancen für den Einsatz konzentrierender Kollektoren in Mitteleuropa. 31. Symposium Solarthermie und innovative Wärmesysteme 2021.
[11] NRW.Energy4Climate. (2023). Wärmewende jetzt gestalten: Mit Strategie zur klimaneutralen Prozesswärme. Praxistipps für Unternehmen. Düsseldorf.
[12] IN4climate.NRW GmbH. (2021). Industriewärme klimaneutral: Strategien und Voraussetzungen für die Transformation. Ein Diskussionspapier der Arbeitsgruppe Wärme. Gelsenkirchen.
[13] Fraunhofer-Institut für System- und Innovationsforschung ISI and Institut für Industrieofenbau und Wärmetechnik (IOB) RWTH Aachen University. CO_2 neutrale Prozesswärme durch Elektrifizierung und Einsatz von Wasserstoff (Policy Brief). Karlsruhe.
[14] Adelphi Consult GmbH and Institut für Wirtschaftspolitik der Leibniz Universität Hannover. (2022). Transformationsstudie zur Dekarbonisierung der niedersächsischen Wirtschaft: Eine explorative Untersuchung zu Wissensstand und Handlungsmöglichkeiten der Transformation in Niedersachsen. Im Auftrag der Niedersachsen Allianz für Nachhaltigkeit. Hannover.
[15] Fraunhofer ISE and Fraunhofer IEE. (2022). Bottom-Up Studie zu Pfadoptionen einer effizienten und sozialverträglichen Dekarbonisierung des Wärmesektors. Im Auftrag des Nationalen Wasserstoffrats. Freiburg, Kassel.
[16] Leicher, J.; Giese, A.; and Wieland, C. (2024). Electrification or Hydrogen? The Challenge of Decarbonizing Industrial (High-Temperature) Process Heat. J 2024, 7, 439–456. https://doi.org/10.3390/j7040026
[17] Hamburg Institut. (2018). Strategische Optionen zur Dekarbonisierung und effizienteren Nutzung der Prozesswärme und -kälte. Commissioned by Hannover Messe and the German Renewable Energy Federation (BEE).
[18] IREES Institut für Ressourceneffizienz and Energiestrategie GmbH and Path to Zero GmbH. (2023). Gutachten zur Dekarbonisierung der Prozesswärmeerzeugung in Hamburg. Karlsruhe.
[19] Zerzawy, S. et al. (2025). Dekarbonisierung der Prozesswärme in der Industrie: Reformoptionen für die prozessbezogenen Entlastungsregelungen bei der Energie- und Stromsteuer. Teilbericht im Rahmen des Projektes „Der Beitrag ökonomischer Instrumente zur Erreichung der Klimaschutzziele: Die Rolle der staatlich bestimmten Energiepreisbestandteile im Instrumenten-Mix. Commissioned by the German Environment Agency.
[20] Meyer, J.; Zaubitzer, L.; Alsmeyer, F.; and Madsen, M. (2024). Kurzstudie: Energieeffiziente und CO_2-freie Prozesswärme. SWK E² Institut für Energietechnik und Energiemanagement, Hochschule Niederrhein. Commissioned by the German Business Initiative for Energy Efficiency (DENEFF).

CONFERENCE TOPIC

1.11. Net-zero/negative Emissions in the Industry including CCUS

ELECTROCHEMICALLY ASSISTED LIQUID-LIQUID EXTRACTION OF LACTIC ACID PRODUCED VIA FERMENTATION

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SUMMARY

To circumvent stoichiometric waste production and lower energy usage of lactic acid (LA) production via fermentation, we propose electrochemically assisted liquid-liquid extraction (EALLX) as a separation method which can extract LA at low concentrations, while regenerating it at a much higher concentration into an aqueous back-extract. The basis for said concentration jump between extraction and back-extraction in our process is an electrochemical solvent which can be switched in an electrochemical flow-cell, by loading the solvent with metal ions via electrode oxidation, which can then form complexes with LA, increasing its affinity towards the organic solvent, and finally breaking the complex by reducing the ions to obtain free LA, which moves towards the back-extraction column. We report here proof of concept of metal oxidation and reduction of metal ions from the solution, and a design of an assembly cell. Key findings include insights into solvent composition impact on the stability of the electrochemical metal oxidation process, and establishing flow patterns within the cell geometry.

INTRODUCTION

The growing drive towards electrification in the chemical industry is largely motivated by the need to reduce carbon emissions and reliance on fossil fuels. EALLX is an innovation aiming to reduce the carbon footprint due to energy intensive solvent regeneration in solvent extraction applications. Although fluid separations can be electrified through various approaches, this project investigates electrochemical switching of solvents to facilitate regeneration, thereby both reducing overall energy demands and making it more eligible to be powered by electricity from renewable sources. Application areas include biobased production of carboxylic acids, or rather platform chemicals. Their fermentative production requires either extensive broth neutralization or *in situ* acid removal at very low concentrations. In this work we focus on extraction of LA.

The importance of LA in general terms comes from the fact that it is a platform chemical and one of its derivatives is polylactic acid (PLA), a biodegradable plastic that has been gaining increasing interest globally. As its market demand is expected to grow [1] production of LA in a conventional manner is revisited to reduce gypsum byproduct formation due to broth pH regulation to maintain metabolic activity of the bacteria, most commonly by using calcium carbonate. Subsequent acidification to obtain LA instead of lactate is performed by addition of sulphuric acid, yielding gypsum in stoichiometric amounts of LA [2], which is undesirable when production is ramped up significantly due to the growing PLA demand.

To remedy that, fermentation with continuous product removal may be applied, however that requires highly effective extraction at low concentrations, and product concentration upon extraction coupled with back-extraction. Our proposed system utilises continuous electrochemical loading and unloading of the organic solvent with metal ions that influence the distribution coefficient (K_D) of LA between the organic and aqueous phase. The solvent is loaded with ions in the anodic chamber of the electrochemical cell by oxidizing the anode, and is

contacted with a pretreated fermentation broth in the extraction column where LA complexes with the metal ions, increasing its tendency to partition into the organic phase. Afterwards the solvent containing LA is reintroduced into the electrochemical cell, in the cathodic chamber, where a reduction of metal ions takes place, resulting in free LA in the organic solvent, which is then extracted into a new aqueous phase in a back-extraction process (Figure 1), which serves as a concentration step, since without metal ions present, the K_D value is notably lower.

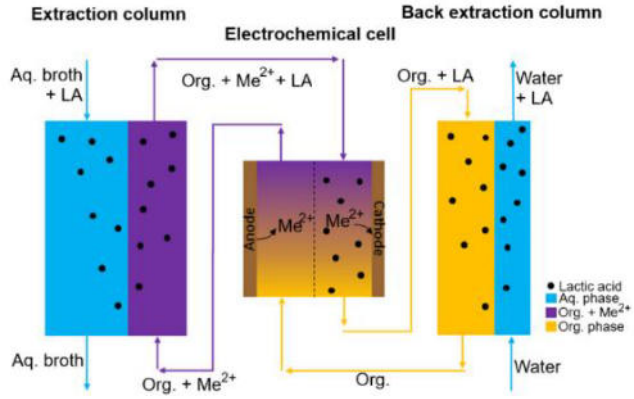


Fig. 1: Schematic representation of the process

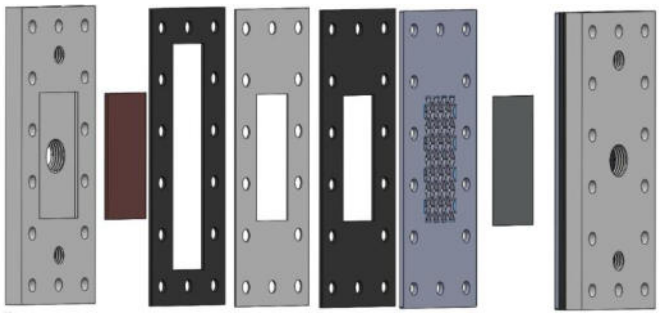


Fig. 2: Exploded view of the electrochemical flow-cell design

For this innovative approach, a sequence of new developments are necessary, including measurement of liquid-liquid equilibria with and without metal ions, and switching of the solvent. We here report on the solvent switching, including both the batch switching results and the design approach for the electrochemical flow-cell for solvent switching applications under atmospheric pressure. The leading design goals were creating a user-friendly and easy to manufacture cell while providing the possibility of easy modification with respect to varying application parameters, such as the need for specific hydrodynamic conditions, residence times, and flow trajectories. The cell features an assembly design (Figure 2) where the desired volume of the cell is created by a series of gaskets and insert panels, which can vary in internal geometry, changing the conditions within the cell, optimizing it to maximize LA extraction efficiency. Although designed for a specific process, the cell holds potential for use in other similar processes due to its easy modification, not being limited to the confines of EALLX.

REFERENCES

[1] URL: https://www.precedenceresearch.com/polylactic-acid-market (access: 02/08/2025)

[2] Singhvi, M., Zendo, T., Sonomoto, K., Free lactic acid production under acidic conditions by lactic acid bacteria strains: challenges and future prospects, Applied Microbiology and Biotechnology (2018) 102

CONFERENCE TOPIC

Biorefinery in a Circular Bioeconomy

SYNERGIZING AUSTRIAN AND CHINESE EXPERTISE FOR CLIMATE-NEUTRAL BUILDINGS: INTELLIGENT FACADES AND DAYLIGHTING SYSTEMS

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SUMMARY

This abstract presents a collective Austrian-Chinese research effort to achieve climate-neutral buildings through intelligent façades and daylighting systems. The collaboration integrates advanced simulations, experimental testbeds, and pilot implementations to develop adaptive façade technologies (dynamic shading, switchable glazing, building-integrated photovoltaics (BIPV), green façades) that maximize energy efficiency and occupant comfort. Key results demonstrate significant reductions in building thermal loads (cooling/heating) and lighting energy use through adaptive control strategies, while generating on-site solar power. The research outputs include validated performance models, cross-climate design guidelines, and case studies in both temperate and subtropical climates. Keywords: climate-neutral buildings; adaptive façades; daylighting; building-integrated photovoltaics; energy efficiency; comfort.

ABSTRACT

This contribution reports an integrated Austrian–Chinese research effort on adaptive façade technologies and daylighting systems, aiming to accelerate the transition towards climate-neutral buildings. The work combines multi-domain simulations, experimental monitoring, and pilot applications to quantify the performance of intelligent building envelopes and to translate findings into validated design guidelines applicable across climatic zones and building types.

A suite of simulation studies was carried out using EnergyPlus, IDA-ICE, DALEC, ENVI-met, and custom algorithms. Adaptive façade elements—including dynamic shading devices, switchable glazing, daylight-redirecting systems, building-integrated photovoltaics (BIPV), and vegetated façades—were evaluated for high-rise office typologies under continental and subtropical conditions. Parametric runs examined annual heating, cooling, and lighting demand, as well as comfort indicators such as spatial daylight autonomy and annual sunlight exposure. Results consistently demonstrated that adaptive façades reduce cooling and lighting energy demand by double-digit percentages compared to static designs. In Guangzhou, dynamic shading combined with daylight-responsive controls lowered cooling loads by up to 35% relative to fully glazed façades, while in Vienna adaptive glazing with tunable solar heat gain coefficients achieved 8–12% annual HVAC energy savings. Integration of daylight-redirecting films increased daylight autonomy by 10–15% without excessive glare, and simulation of BIPV louvers showed that real-time tilt optimization can balance power generation with reduced cooling and lighting demand, improving the overall energy balance of office spaces.

Complementary experimental campaigns were conducted to validate the simulations. A façade-in-the-loop test box equipped with dense heat-flux instrumentation allowed precise determination of variable U-value wall elements and switchable glazing. Measurements confirmed rapid transitions in thermal resistance, with reductions in conductive heat flow of more than 50% under cold-climate operation. Outdoor test rigs for BIPV façades quantified both photovoltaic yield and thermal buffering; comparison with model predictions yielded deviations below 7.5%, confirming the reliability of the developed façade energy model. Vertical greenery prototypes demonstrated solar attenuation of approximately 45% at midday, leading to 3–5 °C lower surface temperatures of the underlying wall. Laboratory photometric characterization of daylighting systems delivered angular solar heat gain and BSDF data, enabling their accurate incorporation into annual daylight and glare simulations. The close correspondence between simulated and measured performance across these setups validates the methodological framework.

The research further established advanced control strategies for integrated façade systems. Using coupled simulations and optimization algorithms, continuous adjustment of roller blinds and PV louvers was shown to decrease cooling energy by ~20% compared to static schedules, while maintaining illuminance within the comfort range. Machine-learning-based controllers demonstrated the feasibility of balancing competing objectives—thermal load reduction, daylight quality, and PV yield—through real-time optimization. These findings highlight the necessity of integrated façade operation rather than isolated component control.

Outcomes from simulation and monitoring were synthesized into a set of design guidelines for adaptive façades. The guidelines cover a spectrum of climates from heating-dominated Central Europe to cooling-dominated Southern China, and address high-rise new construction as well as renovation of existing towers. They include performance ranges for glazing transmittance and insulation, recommended geometries for shading and light-redirection devices, control logics for different climatic zones, and integration principles for BIPV and vegetated façades. Validation through case studies in both Austria and China confirmed that these guidelines ensure compliance with local standards while maintaining high energy performance. The structured documentation provides architects and engineers with a basis for selecting and configuring adaptive façade elements according to climate, building typology, and performance targets.

In conclusion, the joint Austrian–Chinese effort has demonstrated, through extensive simulations and experimental validation, that adaptive façades and daylighting systems can substantially reduce building energy demand while maintaining comfort and generating on-site renewable energy. Quantified benefits include reductions of 10–35% in HVAC and lighting demand, validated through monitoring within ±10% accuracy; improved daylight availability by up to 15% without glare; and effective integration of BIPV systems with adaptive shading. The design guidelines derived from this work translate complex scientific findings into actionable strategies for practice, providing a robust foundation for climate-neutral building design across diverse contexts. This integrated approach illustrates how transnational scientific collaboration can deliver scalable, evidence-based solutions to meet the pressing goal of zero-carbon buildings.

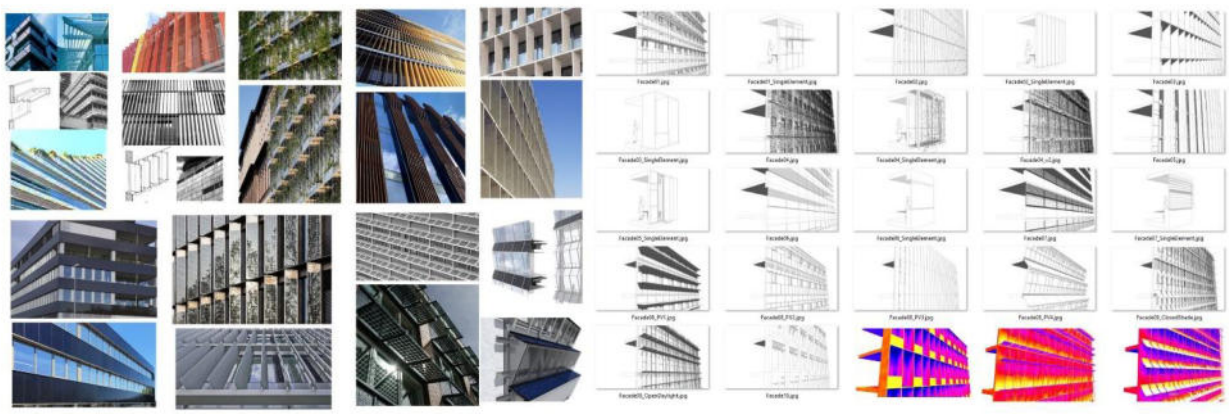


Fig. 1: Adaptive Façade Solutions

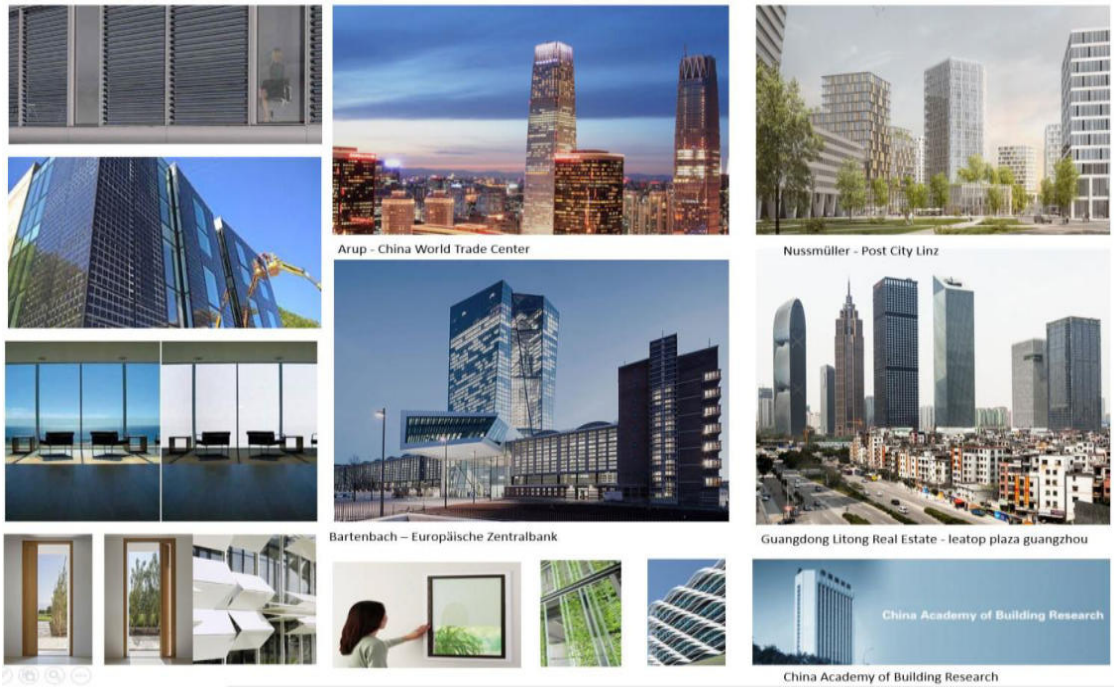


Fig. 2: Use Cases in Cina and Austria

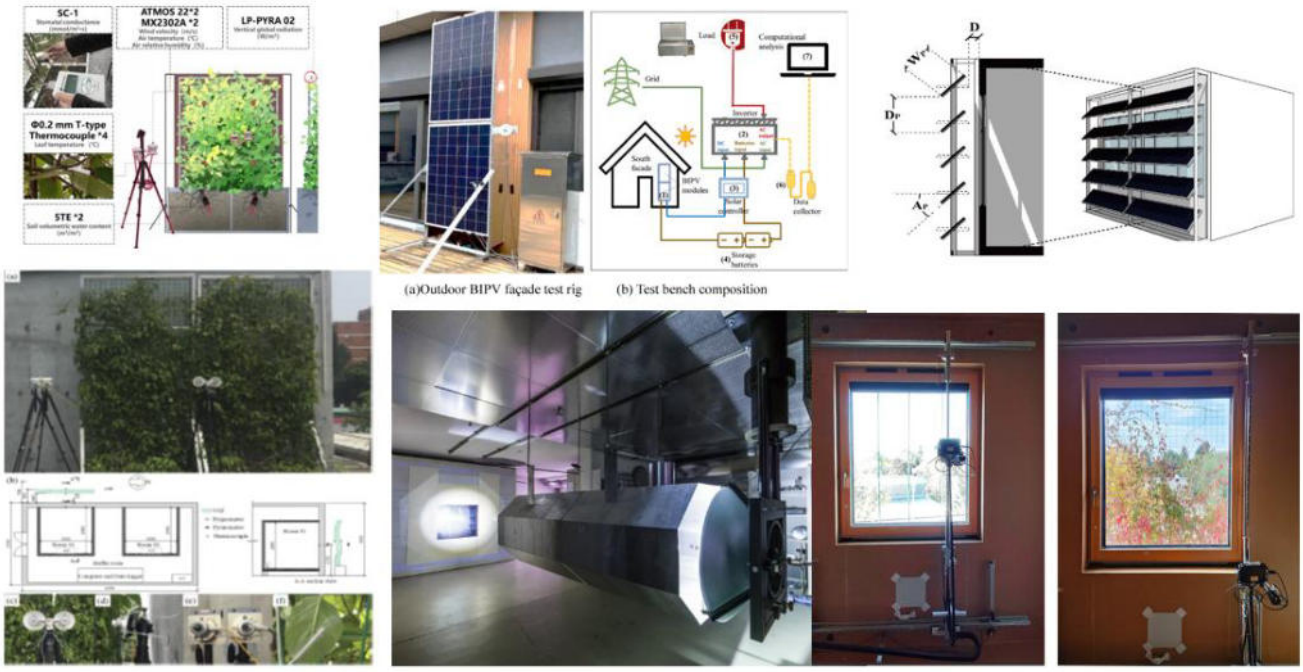


Fig. 3: Laboratory Testing

REFERENCES

- Weiss, T., & Zhang, S. (2024). TechAdZero – Adaptive Facades for Nearly Zero-Energy High-Rise Buildings (Final Report). AEE INTEC & SCUT, Graz, AT / Guangzhou, CN.
- Wong, J. T. L. (2022). Advanced Control Strategies for Adaptive Façades – A Comparison between the Climate in Austria and China (Master's Thesis). University of Applied Sciences Upper Austria, Wels, AT.
- Geisler-Moroder, D., Knoflach, C., & Hauer, M. (2023). Photometric Characterization of Adaptive Daylighting Systems for Building Simulation. Bartenbach GmbH, Innsbruck, AT.
- Nie, Z., & Liu, J. (2024). Optimization of Adaptive Window Thermal Performance in Diverse Climates. China Academy of Building Research, Beijing, CN.
- Gao, M., et al. (2024). Thermochromic Glazing for Energy-Efficient Building Applications – Performance in Different Climates. South China University of Technology, Guangzhou, CN.

CONFERENCE TOPIC

Transform Cities: Holistic Approaches to Sustainable Urban Energy

ELECTRICITY PRICE-DRIVEN CONTROL OF HEAT PUMPS IN INDUSTRIAL DICSTRICT HEATING PROSUMER SUBSTATIONS

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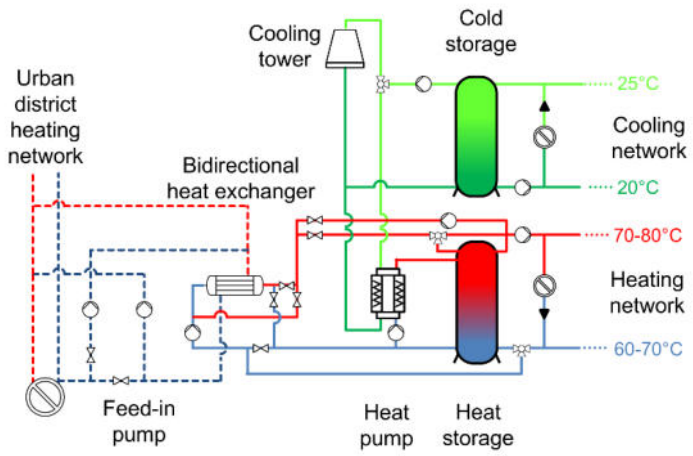
SUMMARY

This study develops an electricity price-driven control strategy for industrial district heating prosumers to utilise low-temperature excess heat via heat pumps. A simulation model is implemented in TRNSYS and includes a model predictive control to optimise heat production and reduce electricity costs. The strategy is evaluated for nine different combinations of heating and cooling load profiles, demonstrating effectiveness in reducing costs during low heating load periods. The results provide insights for the transformation of district heating systems towards a more sustainable and efficient heat production.
Keywords: Industry, district heating prosumer, heat pump, electricity price-driven operation, TRNSYS simulation

INTRODUCTION

District heating systems are widely recognised as an important technology for decarbonising heat supply in many European cities. However, district heating operators, particularly in Germany, face the challenge of transforming their heat production away from fossil fuel-based combined heat and power plants. This work therefore investigates how industrial sites connected to urban district heating systems can act as prosumers in the district heating grid by utilising low-temperature excess heat via heat pumps. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the hydraulic concept of the prosumer substation, which was developed as part of a case study at a German industrial site. The proposed heat pump is integrated in parallel with existing cooling towers, and the bidirectional heat exchanger and the existing feed-in pumps enable both heat consumption and heat feed-in into the district heating grid. The study focuses on developing an electricity price-driven control strategy for industrial district heating prosumers.

FIG. 10: SCHEME OF THE PROPOSED INDUSTRIAL DISTRICT HEATING PROSUMER SUBSTATION



METHODOLOGY

A model of the industrial district heating prosumer has been implemented in the simulation software TRNSYS (Klein et al., 2017). A basic control strategy, based on cooling and heating demand and storage temperatures, serves as a reference case. The electricity price-driven operation of the heat pump is achieved through a model predictive control by coupling the TRNSYS simulation with Type 3157 (Bernier et al., 2022) to an optimisation model in the Python library PYOMO (Bynum et al., 2022). The simplified mathematical model of the prosumer substation in PYOMO aims to minimise operational expenditure within the 24-hour forecast horizon, considering variable electricity prices, and provides an operational schedule for the heat pump, the cooling tower, and the bidirectional heat exchanger in the TRNSYS simulation. Based on annual simulations in TRNSYS, the levelised cost of heating and cooling at the industrial site are calculated. To increase the transferability of the results to other locations, the electricity price-driven control strategy is evaluated for nine combinations of heating and cooling load profiles. The seasonality of the heating load profile is reduced by decreasing the share of the demand for heating purposes. At the same time, the cooling load profile, which is independent of ambient temperature and has a weekly characteristic, is scaled linearly. This results in ratios of cooling demand (excess heat) to heat demand ranging from 0.23 to 1.14. The dimensions of the heat pump, as well as the cold and heat storage are individually adjusted to each combination of load profiles, and the impact of increased capacities on the control strategy is discussed.

RESULTS

The first results showing the effectiveness of the control strategy for a heating load profile with medium seasonality are presented in **Fehler! Verweisquelle konnte nicht gefunden werden.**. For the shown case, the ratio of cooling demand to heating demand is 0.57 for the whole year and 2.32 during summer (June to August), with cooling demand exceeding heating demand for 39% of the year. Throughout the day, the day-ahead electricity price in Germany (upper boxplot) follows a characteristic curve during summer, with peaks in the morning and evening and a trough during the day, when electricity production from photovoltaic systems is at its highest. Consequently, the heat pump operation (lower boxplot) is avoided during price peaks. In winter, the electricity price curve is flatter, with less significant price peaks. At the same time, the heating load is high, so that the heat pump operates despite electricity price peaks, as this is still more cost-efficient than drawing heat from the district heating grid. Although the heat pump operates rather continuously with 5900 full load hours, the control strategy reduces the total heat pump electricity costs by 4.3 %, or by 9.3% with regard to only the

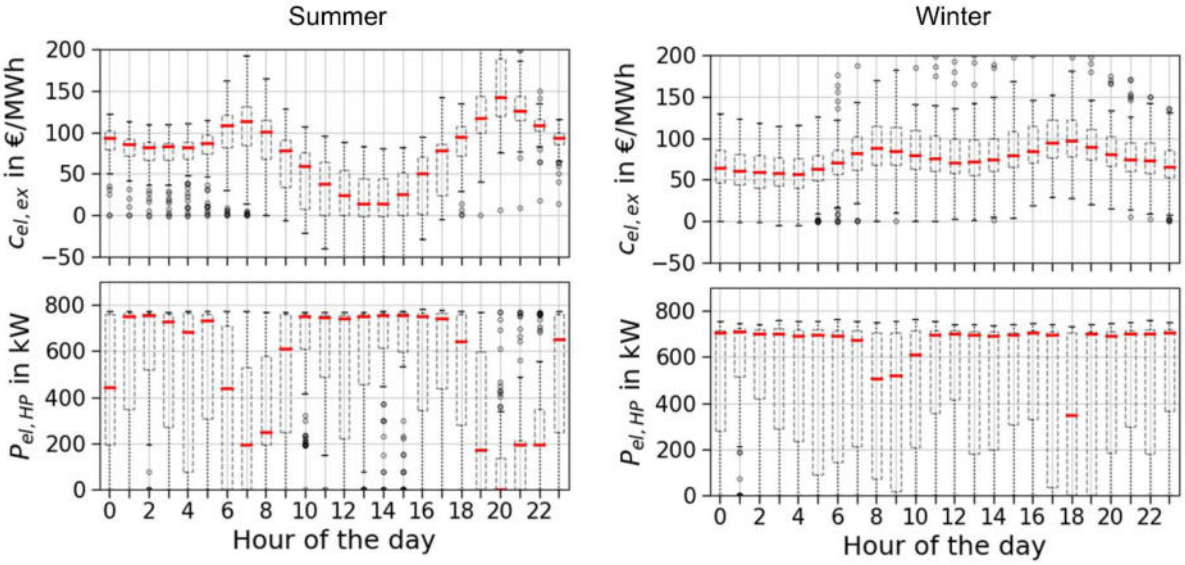


Fig. 11: Electricity exchange price ($c_{el,ex}$) and electricity consumption of the heat pump ($P_{el,HP}$)

variable component of the electricity price.

REFERENCES

Bernier, N., Marcotte, B., Kummert, M. (2022), Calling Python from TRNSYS with CFFI. Polytechnique Montréal. https://doi.org/10.5281/zenodo.6523078

Bynum, M.L., Hackebeil, G.A., Hart, W.E., Laird, C.D., Nicholson, B.L., Siirola, J.D., Watson, J.-P., Woodruff, D.L. (2021), Pyomo — Optimization Modeling in Python. 3rd Edition. Springer International Publishing, Cham.

Klein, S.A., et. al (2017), TRNSYS 18. A Transient System Simulation Program. Solar Energy Laboratory, University of Wisconsin, Madison, USA.

CONFERENCE TOPIC

1.04. Coupling of Energy Sectors
1.06. Excess Heat and Resource Recovery from Low-grade Sources
1.10. Industrial and Urban Symbiosis

ASSESSING MODEL SENSITIVITIES IN DISTRICT HEATING PLANNING: A CASE STUDY USING A PYTHON-BASED TOOLCHAIN

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SUMMARY

When planning new district heating networks (DHN), several challenges must be considered. These include decentralization and fluctuations in renewable energy sources. This contribution presents a case study comparing professional planning of a district heating network in Meersburg (Germany) with various designs generated by an automated Python-based toolchain. The study evaluates the network topologies generated by the automated toolchain in comparison to planner-designed networks and highlights the importance of appropriate heat pump models in the planning process. Based on this comparison, the paper aims to discuss potential benefits of automation, sensitivities of the applied models, and current limitations of the toolchain in early-stage district heating network planning.
Keywords: District Heating, DHC, Thermo-Hydraulic Simulation, Spatial Energy Planning, GIS, Heat Pumps

INTRODUCTION

In Germany, district heating networks supply approximately 14% of residential heat supply (Sayegh et al., 2018), and the successful development of networks based on renewable heat is seen as crucial for the energy transition. The integration of renewable, often decentralized heat sources poses new challenges in early conceptual planning stages compared to the planning of purely combustion-based systems characterized by on-demand scalability of the output. Planning tools must now allow for the simulation of diverse load and supply configurations as the supply is increasingly intermittent and temperature sensitive. Current commercial tools often focus on individual aspects separately, such as heat demand, energy models of heat producer stations, or thermo-hydraulic modeling of the network. As a result, feasibility studies often combine several tools, requiring the exchange of time series and spatial data. Within the TrafoWaermeNetz R&D project (Verbundvorhaben EnEff:Wärme: TrafoWaermeNetz, FKZ 03EN3093 A-F), we are developing a Python-based toolchain that combines consumer demand modeling, optimal network layout generation, and producer simulations including district heat pumps. As a use case, we consider the district heating network in Meersburg, which is currently being planned to extract heat from Lake Constance and distribute it to the town's buildings.

METHODOLOGY

The developed Python-based toolchain builds upon several existing open-source tools and incorporates open data sources. To set the design conditions, the building demands need to be defined. Specific energy demands for the German building stock are derived from Walberg (2011) based on construction year and modernization status. Building footprints are extracted from OpenStreetMap (OSM). The heated area is calculated from the ground floor area and the number of floors. Domestic Hot Water (DHW) consumption is assumed based on the number of residents per apartment according to the norm DIN V 18599. Where parameters are missing, statistical assumptions are applied.

After each building has been assigned a yearly space and DHW consumption, load profiles are generated with the tool *lpagg* (Zimmermann 2021) based on the guideline VDI 4655 and adjusted for simultaneity effects. This results in a peak load which is then used for the network routing. Possible pipe routes are defined by extracting streets and pathways from OSM. The tool *dhnx* (Röder et al., 2021) optimizes the pipe routing and nominal diameters by minimizing total pipe costs while allowing for sufficient transport of heat at the peak load. Subsequently, a thermo-hydraulic simulation is performed with *pandapipes* (Lohmeier et al., 2020).
The resulting network topology for the considered variants is compared with the planners' design, which already takes into account the terrain specificities of Meersburg with its elevation and shortest routes apart from streets (Figure 38). The thermo-hydraulic simulation shows the temperature distribution across the network during operation and its impact on the heat pump efficiency.

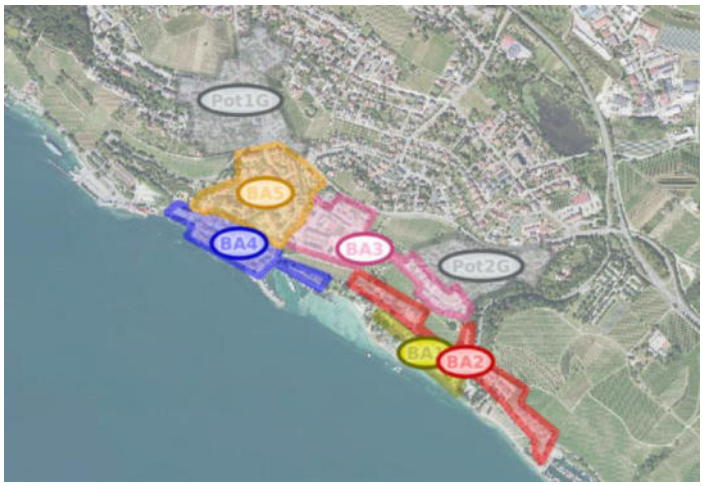


Figure 38: Area considered for the district heating network in Meersburg (Seewärme Meersburg, 2025)

REFERENCES

Deutsches Institut für Normung e. V. *DIN 18599: Energetische Bewertung von Gebäuden – Methodik zur Berechnung des ganzheitlichen Energiebedarfs für Heizung, Kühlung, Warmwasser, Beleuchtung und weitere elektrische Verbraucher*

Lohmeier, D., Cronbach, D., Drauz, S.R., Braun, M., Kneiske, T.M., (2020), Pandapipes: An Open-Source Piping Grid Calculation Package for Multi-Energy Grid Simulations. *Sustainability* 2020, 12, 9899

Röder, J., Meyer, B., Krien, U., Zimmermann, J., Stührmann, T., & Zondervan, E., (2021). Optimal Design of District Heating Networks with Distributed Thermal Energy Storages – Method and Case Study. *International Journal of Sustainable Energy Planning and Management*, *31*, 5–22. https://doi.org/10.5278/ijsepm.6248

Sayegh, M.A., Jadwiszczak, P., Axcell, B.P., Niemierka, E., Bryś, Jouhara, H., (2018), Heat pump placement, connection and operational modes in European district heating, Energy & Buildings 166, 122-144, https://doi.org/10.1016/j.enbuild.2018.02.006

Seewärme Meersburg, (2025), *Nahwärme für Sie.* https://www.seewaerme-meersburg.de/de/Nahwaerme-fuer-Sie/Nahwaerme-fuer-Sie.html (accessed: Aug. 28 2025)

Verein Deutscher Ingenieure e. V. *VDI 4655: Reference load profiles of residential buildings for power, heat, and domestic hot water as well as reference generation profiles for photovoltaic plants*

Verbundvorhaben EnEff:Wärme: TrafoWaermeNetz - Einsatz von Wärmepumpen für die Transformation von Wärmenetzen - Energiewirtschaftliche Bewertung, Planung, Umsetzung und Betrieb, Förderkennzeichen 03EN3093 A-F (2024-2026)

Walberg, D., (2011), "Wohnungsbau in Deutschland 2011 – Modernisierung oder Bestandsersatz", Mauerwerk, vol. 15, no. 5, pp. 294–300, doi: 10.1002/dama.201100508

Zimmermann, J., (2021), *lpagg*. github. https://github.com/jnettels/lpagg (accessed: Aug. 22 2025)

CONFERENCE TOPIC

This abstract refers to the following Conference Topics:

- Future District Heating and Cooling Solutions
- Spatial Energy Planning with Emphasis on Renewable Energies

DEVELOPMENT OF IMPROVED HEAT SOURCES FOR A NEW GENERATION OF COLD DISTRICT HEATING SYSTEMS

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SUMMARY

The purpose of cold district heating systems is to cover the heating and cooling demand of consumers connected to the district heating network. Generally, they consist of a thermal energy source, a thermal energy store, heat pumps and a cold district heating network for distribution. Some of these cold district heating systems use for the heat pumps thermal energy sources like an ice store or solar thermal air-brine-collectors supplying temperatures below the freezing point of water and therefore in these conventional cold district heating systems a mixture of water and antifreeze as heat transfer medium is used. As the use of antifreeze leads to ecological and economic disadvantages, the development of a new generation of cold district heating systems with water as heat transfer medium is being performed. In this contribution to the ISEC conference several investigations with the objective to improve the solar thermal air-brine-collectors and the ice store are being presented. The main focus here is on the heat transfer between heat transfer medium and the water in the ice store resp. the air surrounding the air-brine-collectors.
Keywords: Cold district heating system, cold district heating network, 5GDHC, heat transfer medium, antifreeze, ice store, solar thermal air-brine-collectors

INTRODUCTION

Cold district heating systems are also known as the fifth generation of district heating and cooling (5GDHC) systems. During the evolution of district heating networks, the temperatures in the network distributing the heat decreased continuously from generation to generation. With the most recent fifth generation this evolution continues towards lower temperatures between -15 and 30 °C. The main reasons to use such systems with low temperatures is the reduction of heat losses to the environment and to increase the efficiency of heat generators such as solar thermal collectors and heat pumps. The use of relatively low temperatures is also supported by the continuously improving energetic building standard that makes it possible to use heating systems with relatively low flow temperatures of around 35 °C. Furthermore, the usage of distribution temperatures below approx. 15 °C also offers the possibility to use the district heating network for both, heating and cooling. However, the supply of domestic hot water is challenging with relatively low temperatures in the network.

NEW GENERATION OF COLD DISTRICT HEATING SYSTEMS WITH WATER AS HEAT TRANSFER MEDIUM

Generally, cold district heating systems consist of thermal energy sources such as solar thermal air-brine-collectors and a thermal energy store like an ice store, heat pumps and the cold district heating network for the distribution of the thermal energy. Some of these systems use thermal energy sources supplying temperatures below the freezing point of water. To perform a heat transfer between the thermal energy sources and the cold

district heating network in conventional cold district heating systems the usage of a mixture of water and antifreeze as heat transfer medium is required.
However, the use of antifreeze results in ecological and economic disadvantages. For example, the use of antifreeze requires several security measures due to the classification of common types as slightly water polluting. Furthermore, the viscosity of the mixture of water and antifreeze is higher, and the specific heat capacity is lower compared to water. This leads to an increased electric energy demand for the pumps. Finally, the mixture of water and antifreeze is significantly more costly than water and the production is associated with additional greenhouse gas emissions.
Therefore, the key aspect of a new generation of cold district heating systems, the replacement of the mixture of water and antifreeze with water in the cold district heating network, was realized in a new system concept. As shown in figure 1, between the heat demand of decentral consumers and the heat supply by solar thermal air-brine-collectors and the ice store the cold district heating network distributes the heat. To transfer the heat into the cold district heating network with water as heat transfer medium a central heat pump is required to increase the temperature. This is necessary as the outlet temperatures of the solar thermal air-brine-collectors and the ice store can vary approximately between -15 to 20 °C. This also requires the use of a mixture of water and antifreeze for the heat transfer between the thermal energy sources and the central heat pump. But after the temperature increase by the central heat pump water can be used as heat transfer medium in the main part of the district heating network. In Addition, substations with decentral heat pumps are located in the respective buildings to cover the heat demand using the cold district heating network as their heat source. In this case the temperature is increased from around 5 to 20 °C to 35 °C which is suitable for floor heating systems.

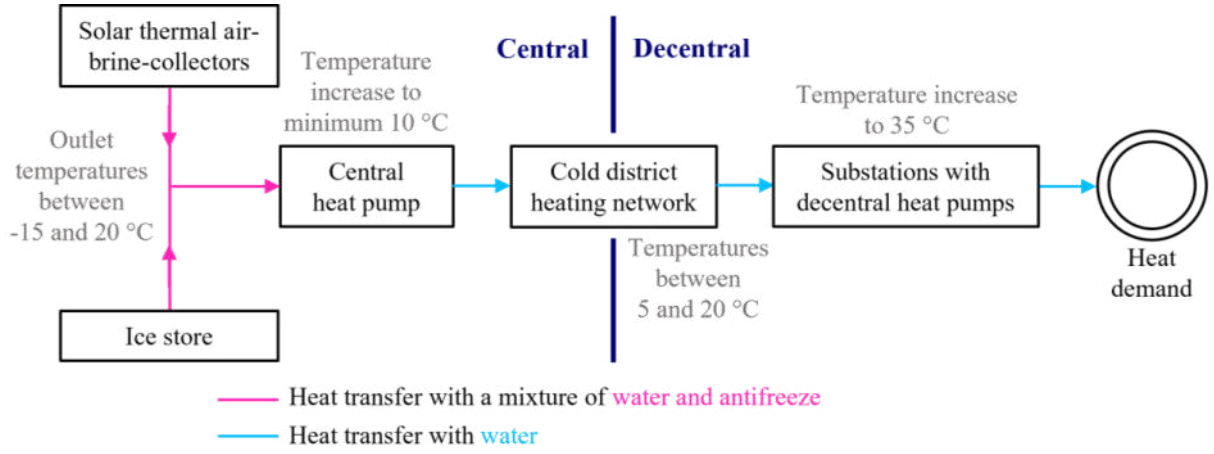


FIG. 39: SCHEMATIC SET-UP OF THE NEW GENERATION OF COLD DISTRICT HEATING SYSTEMS SUPPLYING HEAT WITH WATER AS HEAT TRANSFER MEDIUM IN THE COLD DISTRICT HEATING NETWORK

Besides heating, the system is also suitable for the extraction of heat from the buildings for cooling purposes in summer. The extracted heat can then be stored in the ice store or dissipated by the solar thermal air-brine-collectors to the environment.

ICE STORE

To store surplus heat in and extract heat from the ice store a heat exchanger is necessary. Up to now one heat exchanger for the regeneration of the ice store and one for the extraction of heat from the ice store is used. In order to reduce material costs and the effort and costs for installation the objective of the actual investigations is the use of only one heat exchanger for both regeneration and extraction. Hereby the challenge occurred that although the heat transfer performance increased by using the larger dimensioned extraction heat exchanger for regeneration the water level decreased too fast. A decreasing water level is normal as the liquid fluid water has a higher density compared to solid water resp. ice. But if the water level is decreasing too fast, a significant part of the ice at the upper part of the extraction heat exchanger is then surrounded by air instead of liquid water and

therefore noticeably more difficult to melt. A second attempt with a lower heat transfer rate is currently being caried out und analyzed.
Additionally, the impact on the heat transfer performance through a forced convection flow inside the store initiated by a pump will be investigated. On the one hand this increases the heat transfer coefficient between the liquid water and the ice attached to the heat exchanger. On the other hand, this could prevent the formation of ice on the heat exchanger over a longer period of time and therefore decrease the heat transfer resistance in this period.
Both measures to improve the heat transfer in the ice store are investigated with continuous regeneration and extraction and with dynamically changing operating modes based on measurement data of ice stores in use.

SOLAR THERMAL AIR-BRINE-COLLECTORS

Solar thermal air-brine-collectors use polyethylene pipes or aluminum profiles with a mixture of water and antifreeze floating through them to extract heat from the surrounding air and absorb solar radiation. In winter, depending on air humidity, air temperature and surface temperature of the pipes or profiles the water vapor contained in the air can form ice around the pipes or profiles. This ice layer effects the conductive heat transfer between the heat transfer medium and the surrounding in a negative way. In Addition, the reduced space between the pipes and profiles through the additional ice effects the air flow and therefore the convective heat transfer. To quantify the effect on the thermal performance of solar thermal air-brine-collectors investigations with three different collectors are conducted in a climate chamber.
In addition, in conditions with less or no wind and solar thermal air-brine-collectors arranged close together basins of cold air can form between the collectors and the roof resp. ground. This has a negative impact on the heat output of the collectors. With flow simulations this effect could be confirmed and various measures to reduce this effect were investigated. For example, the bottom row of absorber pipes was omitted and the distance between the collectors was increased.

In the full paper of this contribution to the ISEC conference investigations of the two measures mentioned above to improve the ice store's efficiency and reduce the costs will be described. In Addition, the investigations of icing at the solar thermal air-brine-collectors and measures to reduce the effect of basins of cold air will be presented.

CONFERENCE TOPICS

- Excess Heat and Resource Recovery form Low-grade Sources
- Future District Heating and Cooling Solutions
- Next-Generation Technologies for Renewable Energy and Resource Efficiency
- Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications
- Emerging Heat and Cold Storage

ACKNOWLEDGEMENTS

The research project "Second generation cold district heating" (SolKaN2.0) is funded by the German Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie "BMWE"), based on a decision of the German Bundestag by the project management organization PTJ Jülich, under grant number 03EN6033A/B/C. The authors gratefully acknowledge this support and carry the full responsibility for the content of this publication.

PERFORMANCE AND LIFE-CYCLE IMPACTS OF RESIDENTIAL HEATING SYSTEMS IN EXISTING HOMES: A COMPARATIVE SUSTAINABILITY ASSESSMENT

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SUMMARY

While in Germany the vast majority of residential heating systems is still powered by fossil fuels, accelerating the transition to renewable sources is essential. To enable investors to make informed choices, the German project "Effizientes Heizen" provides an integrated, cross-technology assessment approach for the comparison of different renewable heating systems according to their environmental and economic performance. The investigated technologies include an air source heat pump with and without solar thermal heating/ gas condensing boiler, a brine-water heat pump with PVT collectors or a ground probe as the heat source and a pellet heating system with solar thermal collectors. Additionally, a gas boiler is given as a reference. This contribution provides insights into the technical performance of the systems through PolySun simulations. Further, a comparative Life Cycle Assessment (LCA) is conducted to evaluate the environmental performance of each system.

INTRODUCTION

In Germany, the heat demand in residential buildings was at 594 TWh, 88% of which was used to provide heating and hot water [1,2]. In 2022, fossil-based heating systems still made up roughly 78% of heating systems in the residential sector [3]. In order to reach the climate target of net-zero in 2045, these heating systems must be replaced by renewable sources in the coming decades [4]. Additional regulations, such as the building energy act from 2024 (Gebäudeenergiegesetz, GEG), aim to further accelerate this transition in the heating sector.

The market for residential heating technologies is diverse, with requirements varying by building standard. Investors face a wide range of options when choosing a sustainable heat source – not only regarding the technology itself but also regarding the energy carriers to be used as well as the system design. While heat pumps have experienced accelerated deployment in the past years, the majority of renewable heat is still provided through different forms of biomass (73%). Solar thermal collectors cover about 5% of the heat demand [5,6]. All these technologies cause environmental impacts in their production and end-of-life phases. However, the use-phase impacts can differ rather significantly. While the operational environmental impacts of a heat pump are mainly attributable to the sourced electricity, there are direct emissions that occur in the combustion of biomass. Since emissions that originate from biomass are classified as biogenic (non-fossil) emissions, they are per definition not counted towards the climate change impacts, making biomass a carbon neutral energy source. Solar thermal collectors do not cause direct emissions in their operation.

To ensure a comprehensive overview of the available options and to make a suitable and sustainable decision, comprehensive environmental and economic information is required. Ensuring cross-technology comparability is essential, enabling investors to make an informed and simultaneously most sustainable choice. The German project "Effizientes Heizen" (Efficient Heating) addresses this gap by developing an integrated assessment framework to evaluate residential heating technologies across environmental and economic dimensions. This contribution presents some of the project results regarding the energetic simulations and the ecological assessment. The focus is on the comparison of heating systems for single family houses from the building stock.

The investigated heating systems are designed in line with the requirements from the GEG. The following technologies are investigated in the project:

- Air source heat pump (A/W HP)
- Air source heat pump with solar thermal heating (A/W HP + ST)
- Air source heat pump with gas condensing boiler (A/W HP + Gas)
- Brine-Water heat pump with PVT collector as a heat source (PVT Heat pump)
- Ground source heat pump (Ground source HP)
- Pellet heating system with solar thermal heating (Pellet + ST)

Additionally, a gas boiler is given as a reference, since this is currently the dominating technology for residential heating in Germany.

METHODOLOGY

Environmental impacts can be assessed by conducting a life cycle assessment (LCA). This is an established approach, and its basic structure is defined in the ISO standards 14040 and 14044. While the standards provide basic methodological requirements and recommendations, they still allow for flexibility to make individual choices that may complicate or even prevent a fair comparison of LCA results. To ensure fair and comprehensive comparability, the harmonization of system boundaries, functional units and impact assessment methods is essential.
In the project this is achieved through a variety of harmonization measures. First, compiling the results of a comprehensive study on German building stock [7], a reference existing single-family house (SFH) has been defined. This house features a total area of 140 m² spread across two stories, with a specific heat load of 70W/m² [8]. Then a standard hourly heating profile for this reference building has been created according to ISO-52016 and using the Test Reference Year from the German Weather Service. The design of the heating systems was then elaborated based on recommendations from the German and Swiss heat pump associations and dimensioned in compliance with the VDI 4645 standards and GEG law. Finally, the systems were simulated over an entire year using Polysun software to evaluate the energy consumption and production of each system.

For a fair comparison, the system boundaries for the assessment are then aligned. They include the heating system with all its components, while the distribution system (e.g. radiators) and the building itself are outside the system boundaries. The functional unit for all systems is 1 kWh of provided heat to cover the heating and hot water demand of the building. The impact assessment methodology is chosen in line with ecological assessments from the building sector (EN15804+A2). Besides methodological choices, also technological parameters must be aligned to ensure comparability. These include for example lifetimes, degradation rates and profiles, end-of-life scenarios as well as the applied electricity mix.

RESULTS

The simulation results provide detailed insights into the systems performance over the course of a year. They allow for a separation between the energy and fuel consumption for each component (heat pump, electrical rod, gas boiler, different pumps) while also providing information on the energy source (e.g., electricity from the grid or from the rooftop PV / PVT). At the same time, the results show the respective sources of the energy supply from the system to the building or the grid (e.g., heat supplied by the heat pump vs. the solar thermal collectors). From an energy efficiency perspective, the ground source heat pump is identified as the most efficient heating system, showing the lowest annual electricity/combustible demand in these simulations.

The environmental impacts are quantified and evaluated using the EN15804+A2 methodology. The functional unit is 1 kWh of heat supplied to cover the heating and hot water demand. The impact assessment results for the climate change category for the investigated heat pump systems as well as a gas boiler system show a reduction of more than 50% in the carbon footprint per $kWht_h$ compared to the gas boiler system. In this comparison, the ground source HP shows the lowest carbon footprint, which is due to the slightly higher efficiency and consequently, the lower electricity consumption by the system. However, it must be noted that a comprehensive environmental impact assessment requires further impact categories to be investigated. This allows to identify and then minimize burden-shifting or trade-offs. In the category resource use, minerals and metals for example differences may be observed since heat pumps require a much more complex material mix than gas boilers. The contribution will therefore not only focus on the carbon footprint but also other relevant impact categories.

REFERENCES

[1] Umweltbundesamt, (2025), Endenergieverbrauch nach Energieträgern und Sektoren. [Online]. Available: https://www.umweltbundesamt.de/daten/energie/energieverbrauch-nach-energietraegern-sektoren#allgemeine-entwicklung-und-einflussfaktoren. [Accessed 25 August 2025].

[2] Umweltbundesamt, (2025), Energieverbrauch für fossile und erneuerbare Wärme. [Online]. Available: https://www.umweltbundesamt.de/daten/energie/energieverbrauch-fuer-fossile-erneuerbare-waerme. [Accessed 25 August 2025].

[3] Becker, S., Hagen, J., Joshi S., et al., (2023), DENA-Gebäudereport 2024, Zahlen, Daten, Fakten zum Klimaschutz im Gebäudebestand.

[4] Bundesministerium für Wirtschaft und Energie, (2021), Neues Klimaschutzgesetz, Bundesregierung setzt sich ambitioniertere Ziele. [Online]. Available: https://www.bundeswirtschaftsministerium.de/Redaktion/DE/Schlaglichter-der-Wirtschaftspolitik/2021/10/14-neues-klimaschutzgesetz.html. [Accessed 25 August 2025].

[5] Bundesverband Wärmepumpe e.V., (2023), Branchenstudie 2023, Marktentwicklung - Prognose - Handlungsempfehlungen.

[6] Umweltbundesamt, (2025), Erneuerbare Energien in Zahlen. [Online]. Available: https://www.umweltbundesamt.de/themen/klima-energie/erneuerbare-energien/erneuerbare-energien-in-zahlen. [Accessed 25 August 2025].

[7] Loga, T., Stein, B., Diefenbach, N., Born, R., (2015), Deutsche Wohngebäudetypologie, Beispielhafte Maßnahmen zur Verbesserung der Energieeffizienz von typischen Wohngebäuden. DOI: https://doi.org/10.13140/RG.2.2.11714.50881.

[8] Chaigneau, M., (2025), Gebäudetyp – Einfamilienhaus (EFH). Factsheet. [Online]. Available: https://www.effizientes-heizen.de/documents/Effizientes-Heizen_Infosheet_Gebaeude_EFH_final.pdf. [Accessed 1 April 2025].

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CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

- 2.04. Life Cycle Assessment
- 1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications

ANALYSIS OF THERMAL STRATIFICATION IN PRODUCTION HALLS AND SOLUTIONS FOR AIR CONDITIONING AND ENERGY EFFICIENCY

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SUMMARY

The temperature distribution in production halls significantly affects machine processing accuracy and energy consumption. Extreme temperature fluctuations and inadequate climatic conditions, such as waste heat and solar radiation, can degrade product quality and raise operating costs. This study experimentally investigates the microclimate in two production halls. The first hall, a modern research building, has a large skylight that leads to high solar gains, impacting the hall temperature and thermal stratification stability. In contrast, the second hall, an older workshop without proper air conditioning, shows significant thermal stratification and overheating from machine waste heat. Based on experimental results, an optimized energy concept is proposed to enhance energy efficiency through the integration of various energy sources and the recovery and reuse of low-grade waste heat.
Keywords: thermal stratification, production halls, waste heat utilization, temperature measurement, energy concept, energy efficiency

INTRODUCTION

The temperature distribution in production halls has a decisive influence on the processing accuracy of machine processes as well as on energy consumption. Extreme temperature fluctuations and inadequate climatic conditions, such as production-related waste heat, solar radiation, and heating systems, can lead to a deterioration in product quality and increased operating costs. This study has conducted experimental research on the microclimatic phenomena in factory workshops and analyzed them in depth. Additionally, a new energy concept has been presented, which aims to connect the factory's waste heat with the thermal energy network to recover residual heat from low-quality sources.

In large production halls, thermal stratification is a common phenomenon where the air temperature in the upper area is often higher than in the working area, resulting in a pronounced vertical temperature gradient [Liu 2024]. This uneven temperature distribution reduces the efficiency of heat distribution, especially during the winter heating period [Wang 2017], and indicates the presence of waste heat in the upper area that has not been effectively utilized. To investigate this, thermal stratification was experimentally measured and evaluated in two different production halls through a series of vertical temperature measurements. The E^3 research factory at Fraunhofer IWU [Schneider 2015], a modern research building with a large skylight, meets fire safety requirements for natural smoke extraction but leads to significant solar heat gain. This condition has a strong impact on the hall temperature and considerably reduces the stability of thermal stratification. In contrast, the second hall, an older production hall from 1970 for processing machine parts without adequate air conditioning, exhibits pronounced thermal stratification. The waste heat generated during production is directly released into the interior, resulting in an overheated and stuffy environment during the summer.

This study also presents a new energy concept (Fig. 1) based on experimental data. Part of the exhaust air from the workshop, which contains excess heat, is used by an air-water heat pump to further increase the temperature of the cooling water for the machines and to supply it to the hot water network. Another part is utilized by a second air-water heat pump for the generation of hot water, which is used for the cleaning machines. The cooled exhaust air exiting from the heat pump can be used in winter to heat fresh outdoor air and in summer to cool outdoor air. The entire system is flexibly adjusted through temperature levels to meet varying seasonal and demand requirements.

Overall, the research on the microclimate in production halls, particularly regarding temperature stratification, has deepened the understanding of the influence of solar radiation, production processes, and other factors on environment temperature, providing a theoretical foundation for new energy concepts. The proposed energy concept integrates various energy sectors and aims to comprehensively recover and reuse low-grade waste heat to support the energy supply of the halls. This approach increases energy efficiency, reduces operating costs, and promotes sustainable development.

FIGURES

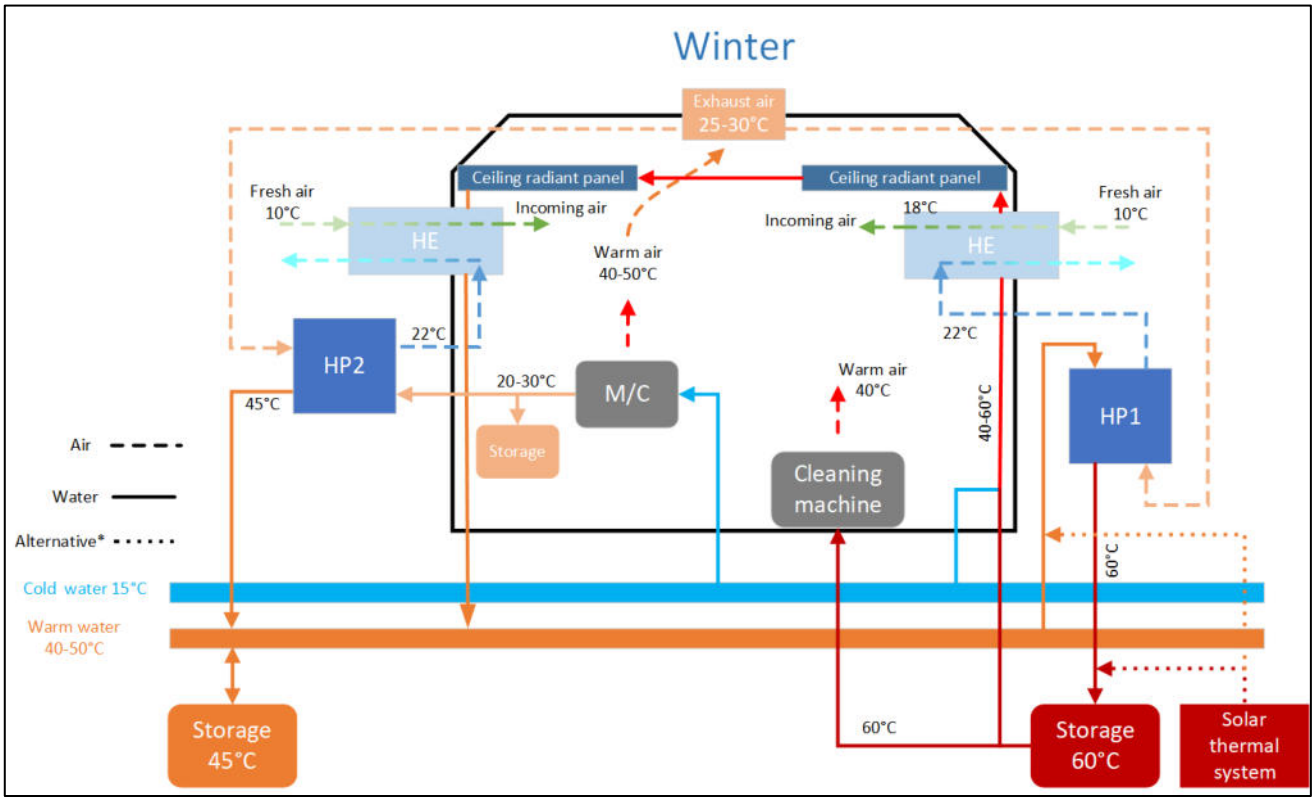


Fig. 1: Energy concept for a production hall in winter

REFERENCES

Liu, X., Liu, X., & Zhang, T. (2024). Dimensionless correlations of indoor thermal stratification in a non-enclosed large-space building under heating and cooling conditions. *Building and Environment*, *254,* 111387.

Wang, L. L., & Li, W. (2017). A study of thermal destratification for large warehouse energy savings. *Energy and Buildings, 153,* 126-135.

Schneider, H. (2015). E3-Forschungsfabrik Ressourceneffiziente Produktion. *Zeitschrift für wirtschaftlichen Fabrikbetrieb*, *110*(4), 225-226.

CONFERENCE TOPIC

“Coupling of Energy Sectors” and “Excess Heat and Resource Recovery from Low-grade Sources”

NOVEL MATERIALS FOR HEAT STORAGE: $CUSO_4$ – PDMS COMPOSITES IN MICROFLUIDIC THERMAL BATTERIES

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SUMMARY

Thermochemical energy storage (TCES) represents a crucial technology to meet the EU Green Deal objectives for carbon reduction. The reaction of copper(II)sulphate with ammonia shows high storage potential (1.77 MJ kg^{-1}) but is limited by severe volume changes during cycling. To address this challenge, we developed a composite material by embedding $CuSO_4$ in a flexible polydimethylsiloxane (PDMS) matrix. First tests confirmed promising performance storing heat at 200 °C. Furthermore, the integration into a microfluidic chip demonstrates a novel reactor concept, exploiting miniaturization for higher efficiency and modular scalability. This approach opens pathways toward customized thermal batteries with high storage density and robust cycling stability.

Keywords: thermochemical energy storage, energy storage materials, microfluidics, composite materials

INTRODUCTION

The EU Green Deal sets ambitious goals to reduce the carbon footprint of all member states by mid-century. In 2016, the European Commission emphasized the key role of the heating and cooling sector in achieving these targets [1].
Thermochemical energy storage (TCES) is a key heat storage technology, offering the highest storage capacities in comparison to the other possibilities. It utilizes reversible reactions of thermochemical materials (TCMs) to store and release thermal energy.
Reactions between transition metal salts and ammonia to form coordination compounds have emerged as highly promising. In particular, the $CuSO_4/NH_3$ system (eq. 1) combines full reversibility over at least ten cycles with a high reaction enthalpy of 1.77 MJ·kg^{-1} [2].

$$CuSO_4 + 4\,NH_3 \rightleftharpoons [Cu(NH_3)_4]SO_4 + \Delta H_r \qquad \text{(eq. 1)}$$

Despite these advantages, a major obstacle remains: the copper ammine complex exhibits a 2.6-fold volume expansion compared to $CuSO_4$. This hinders classical reactor designs such as fixed- or packed-beds. Porous host matrices (e.g. zeolites) alleviate the expansion issue but significantly compromise storage capacity [3].

To address this challenge, we introduce a novel strategy: embedding $CuSO_4$ into a flexible polydimethylsiloxane (PDMS) matrix to form adaptive composite materials.

RESULTS

High-performance composites were fabricated with a composition of 1 part PDMS and 1.25 parts $CuSO_4$. While the target operating temperature is ~200 °C, further optimization is ongoing.
In the next step the composites were included in a microfluidic chip to investigate a new reactor concept and exploring the potential of microfluidics and rapid prototyping for heat storage reactors.
The chip represents the smallest functional storage unit; by combining multiple units, modular "thermal batteries" can be assembled. This modular design allows tailoring to specific applications and simplifies scale-up. Figure 40 provides a graphical representation of our system.

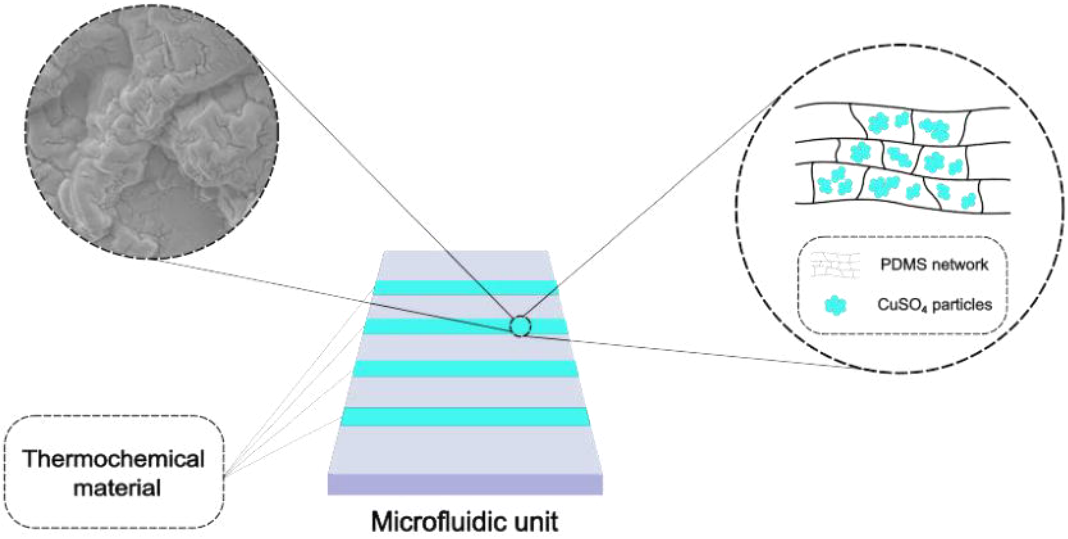


FIGURE 40: GRAPHICAL SCHEME OF THE CONCEPT

A part of this idea is protected by patent A 50736/2023 („Vorrichtung zur Speicherung von thermischer Energie").

ACKNOWLEDGEMENTS

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REFERENCES

1. *Towards a smart, efficient and sustainable heating and cooling sector*. 2016, European Commission: Brussels.
2. Müller, D., et al., *Medium-temperature thermochemical energy storage with transition metal ammoniates – A systematic material comparison.* Applied energy, 2021. **285**(ISSN: 0306-2619).
3. Müller, D., et al., *$CuSO_4/[Cu(NH_3)_4]SO_4$-composite thermochemical energy storage materials.* Nanomaterials, 2020. **10**.

CONFERENCE TOPIC

1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

PREDICTING AND DETECTING DHW LOSSES IN LOW-ENERGY BUILDINGS WITH A DIGITAL TWIN

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SUMMARY

As part of the Campagne Innsbruck Monitoring Project, a digital twin (DT) of the domestic hot water (DHW) system in a Passive House residential quarter (four multi-family buildings containing 307 apartments) was developed. During the pre-design phase, a white-box model was created to estimate distribution losses and overall system performance of different HVAC variants, leading to the choice of decentralised DHW preparation via fresh water stations (FWS), which are supplied by district heating. However, the measured distribution losses during operation significantly exceeded the simulation results. To address this discrepancy, additional monitoring, including infrared imaging and high-resolution temperature measurements, was implemented. The extended dataset enabled calibration of the DT, revealing that the primary cause of the elevated losses was the excessive preset bypass temperatures of the uninsulated FWS. After adjusting the bypass settings on two risers, the distribution losses were reduced by approx. 30%, and this confirmed the DT predictions. This approach shows how combining (pre-) design models with monitoring data can enhance system reliability, highlight hidden inefficiencies and facilitate the data-driven operation of highly energy-efficient buildings.

INTRODUCTION

Digital twins (DT) are increasingly central to the design, commissioning and operation of energy efficient buildings (Ferré-Bigorra et al., 2022; Ochs et al., 2024). These models can support system simulation, performance validation and real-time fault detection and diagnosis (FDD) by continuously integrating monitoring data to represent actual behaviour (Crespi et al., 2023). (Hodavand et al., 2023) reports that data driven models are gaining popularity, but recommends the development of interpretable models to enable all benefits of a DT. Distribution losses from DHW systems play an important role in highly energy-efficient buildings such as Passive Houses, where they represent a significant uncontrolled heat source (Hamburg et al., 2021). In summer, these losses can contribute to unwanted overheating or increased cooling demand. In conventional DHW systems with circulation pipes, high supply and return temperatures (>55°C) must be maintained to meet hygienic requirements, particularly regarding legionella prevention (ÖNORM B 2531:2024-10), resulting in high distribution losses. With the increasing integration of heat pumps (HP) for low-temperature supply, reducing system temperatures becomes essential (Toffanin et al., 2022).

METHOD

During the preplanning phase of the Campagne Innsbruck Area a detailed white-box model of the DHW distribution was developed. The model focuses on thermal representations of the distribution network and FWS, with a particular focus on standby and distribution losses. This DT served as a planning tool for system sizing, expected energy demand, and assessment of efficiency under different operational scenarios (e.g., circulation-based distribution vs. decentralized preparation, varying heat generation). (Dermentzis et al., 2021) already concluded for this case study that the most efficient distribution system for a combined heat generation via groundwater HP for space heating and district heating for DHW preparation is the so called 4P-FWS (2+2 pipe distribution with decentral FWS). To validate and calibrate the model, an extensive monitoring system was installed. Heat meters were positioned at strategic locations in the distribution network and directly at the primary site of the FWS in one building. Temperature sensors with higher temporal resolution were added later to capture

transient system behavior and bypass operation more accurately. Complementary infrared measurements of the FWS were carried out to quantify localized heat losses not covered by the standard instrumentation. After calibration, the DT was integrated into a continuous commissioning approach. The validated model now functions as a tool for FDD and operational optimization, enabling the identification of abnormal system behavior (e.g., elevated return temperatures, excessive standby losses) and supporting decision-making for further efficiency measures, such as insulating FWS or adapting system control strategies.

RESULTS

The initial comparison between model predictions and monitored data revealed substantially higher distribution losses in operation than in simulation. A stepwise calibration of the DT was performed based on additional measurements and allowed refining model assumptions. The reduction of the flow temperature is limited by comfort requirements, but experience shows that limiting the return temperature by reducing the mass flow by the preset bypass of the FWS can reduce thermal losses significantly without violating comfort. Monitoring showed that reducing the return temperature to approx. 30 °C in eleven of the twelve apartments of two risers (C6 and C7, see Fig. 1), distribution losses were reduced by about 30%. These losses consist of thermal losses from the distribution pipes (partially inside and outside the thermal envelope) as well as standby losses from the uninsulated FWS (within the thermal envelope). The exact share of these components is currently being quantified.

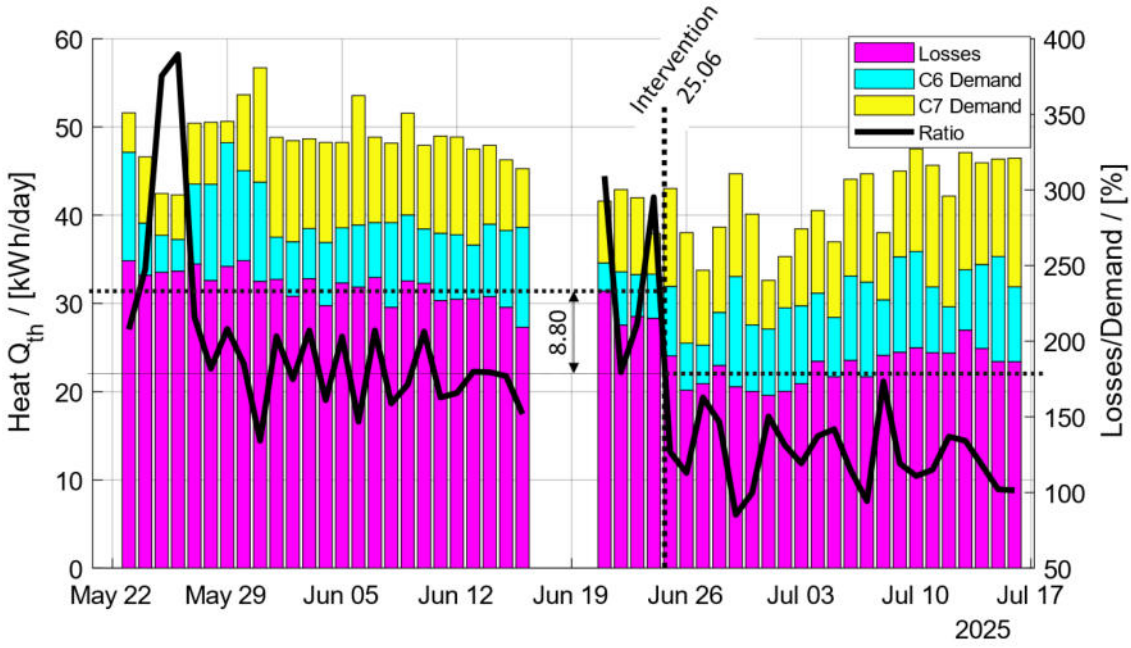


Fig. 1: Daily DHW demand of the apartments in C6 and C7 and distribution losses as well as the ratio of losses to demand (secondary axis).

By continuously integrating monitoring data, the DT evolves into a powerful tool for identifying inefficiencies and supporting data-driven decision-making. In the future, coupling the DT with an energy management system (EMS) could transform it from a passive monitoring instrument into an active control entity, enabling FDD and adaptive operation.

REFERENCES

Crespi, N., Drobot, A. T., & Minerva, R. (2023). The Digital Twin. *The Digital Twin*, *1–2*, 1–1238. https://doi.org/10.1007/978-3-031-21343-4/COVER

Dermentzis, G., Ochs, F., Thuer, A., & Streicher, W. (2021). Supporting decision-making for heating and distribution systems in a new residential district - An Austrian case study. *Energy*, *224*, 120141. https://doi.org/10.1016/J.ENERGY.2021.120141

Ferré-Bigorra, J., Casals, M., & Gangolells, M. (2022). The adoption of urban digital twins. *Cities*, *131*, 103905. https://doi.org/10.1016/J.CITIES.2022.103905

Hamburg, A., Mikola, A., Parts, T. M., & Kalamees, T. (2021). Heat Loss Due to Domestic Hot Water Pipes. *Energies 2021, Vol. 14, Page 6446*, *14*(20), 6446. https://doi.org/10.3390/EN14206446

Hodavand, F., Ramaji, I. J., & Sadeghi, N. (2023). Digital Twin for Fault Detection and Diagnosis of Building Operations: A Systematic Review. *Buildings 2023, Vol. 13, Page 1426*, *13*(6), 1426. https://doi.org/10.3390/BUILDINGS13061426

Ochs, F., Magni, M., Dermentzis, G., Monteleone, W., & Venturi, E. (2024). Towards Digital Twin - Holistic Planning of Thermal Renovations with Heat Pumps in Multi-apartment Buildings. In U. Berardi (Ed.), *Multiphysics and Multiscale Building Physics* (pp. 11–17). Springer Nature Singapore.

Toffanin, R., Caputo, P., Belliardi, M., & Curti, V. (2022). Low and Ultra-Low Temperature District Heating Equipped by Heat Pumps—An Analysis of the Best Operative Conditions for a Swiss Case Study. *Energies 2022, Vol. 15, Page 3344*, *15*(9), 3344. https://doi.org/10.3390/EN15093344

CONFERENCE TOPIC

1.05. Digitalization for Smart, Resilient Energy Systems
1.08. Future District Heating and Cooling Solutions

FACTORS THAT INFLUENCE USER SATISFACTION DURING SERIAL BUILDING RENOVATION PROJECTS

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SUMMARY

Serial building renovations are an innovative solution to improve the energy efficiency of existing buildings. However, for serial building renovations to be successful, it is essential that the users or residents of the existing buildings experience minimal disruption during the renovation process. Within the "RENVELOPE" project, different demonstration sites will be evaluated before, during, and after the serial building renovation process. This paper describes the evaluation of the renovation process at one of the demonstration sites, a vocational school in Knittelfeld. 23 participants, mainly teachers and directors, took part in an online survey from December 2024 to January 2025 to evaluate their satisfaction during the renovation phase of the project. The findings showed that the satisfaction for different aspects of the renovation process were mainly evaluated as fully or partially fulfilled. The most important factors during the renovation phase seemed to be the continuation of ongoing school operations, quick responses to queries and communication of relevant topics.

ABSTRACT

Background Information: The building sector is responsible for a significant proportion of greenhouse gas emissions. Therefore, within this sector, there is potential to save energy and protect the environment through innovative technical solutions. One way to reduce greenhouse gas emissions in this sector is through serial building renovations. Serial building renovation means that certain parts of the renovation materials and products are pre-built before the renovation process begins. As a result, the on-site renovation process can be carried out more quickly. Furthermore, the focus on energy efficiency during the renovation process can help make existing buildings more energy efficient (Umweltbundesamt, 2021). Within the project "Renvelope", the concept of serial building renovations is being tested and evaluated on three different demonstration sites. One of these demonstration sites, a vocational school in Knittelfeld, has been evaluated both before and during the renovation process. The existing school building was renovated using new building envelopes, with the goal of making the building more energy efficient and sustainable. One major goal of the renovation process was, however, to ensure that the users (in this case the teachers and directors) were affected as little as possible by the renovation process at school, to ensure the continuity of school operations (Renvelope, 2025).
Method & Participants: To evaluate the renovation process, 45 participants (teachers and directors) were contacted, of which 23 responded (51.1%). 18 participants were male, 4 were female, and 1 person did not specify their gender. The ages of the respondents ranged from 38 to 58 years. Most of the participants held a university degree (19 out of 23 participants). The main educational background of most of the participants was technical, as the school prepares for various technical professions. The study was carried out from December 2024 to January 2025 through an online survey. In the first part of the study, participants had the opportunity to indicate whether certain aspects of the renovation process were fulfilled as "fully", "partially" or "(not) yet", with an additional option of "I don't know". Afterwards, participants were asked to evaluate the aspects that were only considered "partially" or "(not) yet" fulfilled, based on how disturbing these aspects were for them. This approach aimed to identify which aspects were already fully fulfilled and which of the factors that had not been fully

addressed should be prioritized in future projects. The satisfaction factors for renovations used in the questionnaire were adapted from Othman (2015).

Results of the study: The results of the online survey showed that satisfaction with the renovation process was primarily evaluated as "fully" or "partially fulfilled" by participants, with only a few responses for the option "(not) yet". For some aspects, participants could not answer the question and selected the option "I don't know".



FIGURE 41: SELECTION OF SATISFACTION FACTORS BY MENTION FREQUENCY

According to the responses (see **figure 1**), the renovation work allowed school operations to continue, mostly evaluated as either "fully fulfilled" (7 participants) or "partially fulfilled" (15 participants). Participants found the renovation process to be carried out with high quality, receiving high scores on "fully fulfilled" (8 participants) or "partially fulfilled" (4 participants). For some participants, it was not possible to evaluate the quality of the work, as indicated by the replies "I don't know", which 11 participants selected for this question. Additionally, the design of the renovation solution and the execution of the renovation were evaluated as "fully" (10 participants) or "partially" (8 participants) promising, with only 2 responses indicating "not yet" promising. The renovation solution was considered future-oriented, according to one of the replies from the open-ended questions. Furthermore, the supervision process was conducted to the satisfaction of the majority of participants either "fully" or "partially". In the next step of the questionnaire, participants had the opportunity to rate the factors that were only partially or not yet fulfilled for them on a scale from "very disturbing" to "not disturbing at all" (very, quite, somewhat and not at all disturbing). This should help identify which factors to concentrate on in further serial renovation processes. It can be noted, that the answer "very disturbing" was used in only a few cases, which shows the understanding of the nature of the renovation process. One of the most important factors seemed to be the continuation of regular school operations, which should proceed as smoothly as possible during the renovation process. Some participants mentioned that, due to temporarily blocked classrooms or noise, regular school operations were partially not possible or less effective. This was indicated as "very" (1 participant), "quite" (6 participants), and "somewhat disturbing" (6 participants). Three participants did not find it disturbing at all. The desire for more communication on relevant topics was selected by 6 participants as "somewhat disturbing" and by 3 participants as "not disturbing at all". A quick reaction to user queries or complaints was marked as "very disturbing" by 2 participants, "rather disturbing" by 1 participant, "somewhat disturbing" by 3 participants and "not disturbing" by 1 person.

Conclusion & Limitation: As a limitation it can be mentioned, that only 23 participants took part in the study. Further evaluations on the demonstration sites should give more insights into the success factors of the renovation processes. Nevertheless, the study showed that the majority of the responses were positive and provided insights into the most important success factors.

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REFERENCES

Umweltbundesamt, (2021), Serielle Sanierung in Europa und Deutschland. Umweltbundesamt, Dessau-Roßlau, Deutschland.

Othman, A. A. E. (2015), An international index for customer satisfaction in the construction industry. International Journal of Construction Management, 15(1), 33-58. https://doi.org/10.1080/15623599.2015.1012140

Renvelope, (2025), Homepage. Retrieved on 14. August 2025 from https://renvelope.at/

CONFERENCE TOPIC:

1.15. Sustainable Renovation and Energy Retrofits

TECHNO-ECONOMIC VIABILITY OF A SOLAR THERMAL STEAM KITCHEN FOR RURAL SCHOOLS OF THE GLOBAL SOUTH

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SUMMARY

Combustion byproducts of cooking indoors is a major cause of respiratory illness in women and children of the Global South. The use of direct-fired woody biomass cooking appliances at institutions such as schools is the predominant method for cooking, however, several initiatives seek to convert fuels by installing Liquified Petroleum Gas (LPG) burners. Where there is a high level of Direct Normal Irradiance (DNI), Concentrated Solar Thermal (CST) offers the opportunity to primarily use the sun's heat energy for cooking to maximize energy sovereignty. This paper describes a CST technology which uses a newly-designed parabolic microtrough made primarily of common materials that is shipped in a compact form and assembled by local labor on site. The array directly generates steam for steam-jacketed kettles, a simple technology well-suited to stewing tough meats and vegetables typical to the cuisine. Thermal storage, in the configuration of a Ruth's-type steam accumulator is employed in the system design, and a combustion boiler backup is provided. A complete ISO container-based kitchen equipped with the kettles is included. Because combustion is removed from the kitchen, draft hood air handling is reduced which then may be accommodated by non-electric means such as natural draft chimneys with auxiliary steam blower nozzles to induce draft. We will size a system and examine the logistics and economics for equipping one or more of the Education Development United Fellowship (EDUF) facilities in Mozambique. We expect to be able to show how the solar thermal and LPG energy sectors can be integrated to use LPG as a resource more efficiently while rapidly and completely changing the working conditions in institutions in the Global South, increasing their resiliency, as well as slowing deforestation.

Keywords: Clean Cooking, Solar Cooking, Global South, Sector Coupling, Energy Storage Systems

INTRODUCTION

The UN World Food Program (WFP) recognises than millions of children go to school on an empty stomach, and that hunger affects their concentration and ability to learn. School lunch programs therefore provide a vital role to fulfil this need. According to CLEAN-Air (Africa), more than 90% of schools rely on green cordwood fuel for cooking, often in cauldrons over large jikos. The resulting poor combustion is a major health hazard to cooks as well as students and faculty in the vicinity. The use of wood fuel is an economic burden to the school and a significant contributer to deforestation. While there are currently initiatives such as those by CLEAN-Air (Africa) in the United Kingdom and Bettering Human Lives and Clean Cooking Alliance in the United States to primarily utilize LPG (Liquified Petroleum Gas) and to a lesser extent grid electricity for cooking, these secondary energy sources are expensive, less resiliant, and less sustainiable solutions. In areas of high Direct Normal Irradiance (DNI), Concentrated Solar Thermal (CST) can supplement a large portion of the energy required directly to steam-jacketed cooking kettles. This cooking tool has been a staple in the galleys of navy ships for more than 100 years and can accomodate cuisines of the global south.

ANALYSIS

A case study of one or more EDUF training schools will be performed to evaluate the cost saving and avoided tons of CO^2 released of deploying a containerized kitchen primarily consisting of steam jacketed kettles. An operational model will be developed for the site which sizes the array and wet steam accumulator thermal storage such that in normal conditions, no LPG gas is necessary. The economic model will utilize a field-assembled, ground-mounted, solar parabolic microtrough which ships to the site as flat-packed kits in bulk. One objective of the training school is to teach students the theory, erection, operation, and maintenance of the solar thermal cooking system so they may successfully deploy a system sized to meet the requirements of their teaching area upon graduation. The impact of these satellite facilities will be estimated along with a preliminary sensitivity analysis of scaling the technology in array size and number of installations.

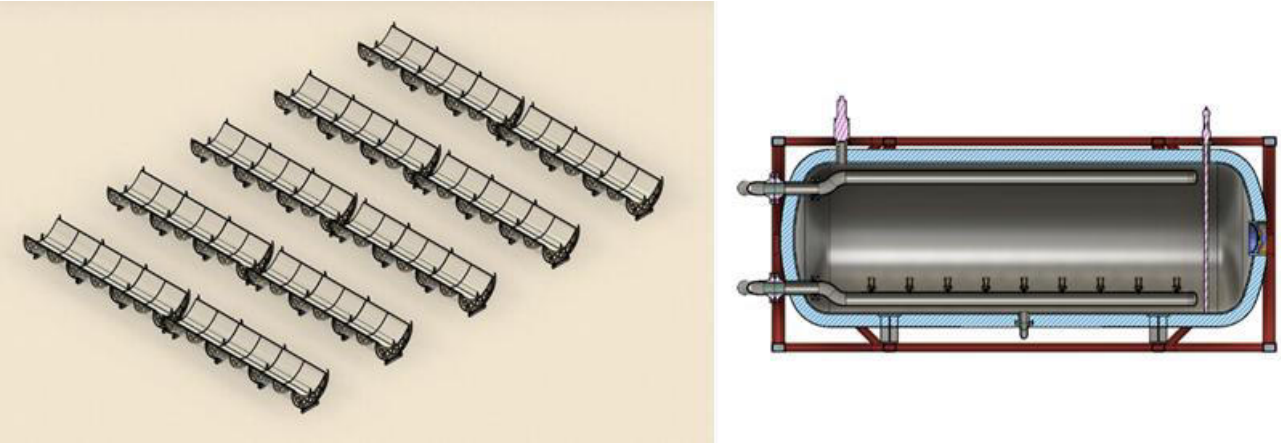


Fig. 1: 88 kWth Field-Assembed Solar Parabolic Micro-Trough Array; ISO-CONEX Wet Steam Accumulator

EXPECTED OUTCOMES

We expect to develop a model to show the array to be able to charge the steam accumulator in the afternoons and the accumulator to have minimal thermal losses such that steam is availiable early in the morning to begin cooking, with the array contributing directly to the thermal load in morning after sunrise. We anticipate the auxiliary and supporting systems to be shown to be simple and manageable. We expect to determine a range of practical plant sizes for this equipment as well as the cost savings and avoided CO2 released of satellite facilities. We expect to find significant savings in transportation costs of the system due to the modular design, the troughs shipping as flat kits, and an effective range where the capital cost and O&M costs of this trough have advantages over factory-built troughs. It is possible that our study will show a scale where technology transfer can occur for manufacturing in the Global South as the troughs do not require specialized machinery to produce, and most other components of the system can already be sourced in the region.

REFERENCES

Nabukwangwa, W., Rutayisire, R., Kalkman-Boudewijns, E. A., Lorenzetti, F., Nix, E., Mutariyani, B., Arthur-Akaranga, G., Koech, B., Kinya, J., Shupler, M., Rosa, G., Puzzolo, E., Mambo Muvunyi, C., Ntakirutimana, T., Pope, D., Musanabaganwa, C., Mwitari, J., & Matthaios, V. N. (2025). Air pollution and health in Rwandan and Kenyan schools cooking with polluting fuels: a cross-sectional impact study. *Environmental Research*, *285*(Pt 4), Article 122619. https://doi.org/10.1016/j.envres.2025.122619

CONFERENCE TOPIC

Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications
Just and Inclusive Mechanism for the Energy Transition for the Global South
Marketing, Dissemination and Implementation Strategies for the Global South

DFLUX – RELIABLE AND FLEXIBLE FLUX SIMULATION TOOL FOR SOLAR AND LIGHT APPLICATIONS

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SUMMARY

When designing receivers or reactors for Concentrated Solar Power (CSP) the exact knowledge of the flux distribution on the surface of such device is crucial for the R&D process. For this, an idealized ray tracing model is being used normally. Here, a novel solution, the dFlux software for differentiable rendering is presented, suitable for versatile solar applications. It makes gradient based workflows more accessible to the wider community in solar research and related fields. The method includes natural and artificial light sources and is flexibly usable for different tasks, ranging from reconstructing deformations to maximizing light on a cavity. It is already successfully evaluated for the solar simulator Synlight® where it was used for inverse rendering tasks, reaching low mean absolute errors.

Keywords: differentiable raytracing, optimizations, software, flux simulation, solar, light

INTRODUCTION

As of now, the landscape for raytracing in solar technology is very fragmented. Most tools are tailormade for narrow scenarios, such as solar towers, or do not offer (design) optimization capabilities. We hope to alleviate this by providing a software offering more general applicability beyond highly specialized scenarios. Also, it needs to be usable for a wider range of knowledge levels, especially engineers not working in raytracer development. To achieve this, we are combining a reusable core library with a flexible graphical user interface.

RELATED WORKS

A basic comparison of the novel tool with some commercial and open-source ones currently in use at our institute can be seen in Table 1. It shows, that dFlux occupies a unique spot in the ray tracing landscape for solar research.

Table 1: Raytracing software in solar research

	Differentiable	Focus Area	Flexible Losses	GUI
dFlux	Yes	General Light Flux Simulations	Yes	Yes
ARTIST	Yes	Solar Towers (including kinematics)	No	No
STRAL	No	General Solar Research	-	Yes
SPRAY	No	Solar Tower or Synlight (different versions)	-	No
Zemax (Commercial)	Limited	General Optics	Limited	Yes

FEATURES

Multiple parts in the software are working together to make gradient-based optimization in solar research as accessible as possible: an entity system, with gradient setup options, an optimization task builder, and various I/O options for convenience and interoperability.

Scenes and gradients can be created using the entity editor. It manages a list of entities, that have properties that can be set to a value, and can have a gradient assigned. Currently, a basic library of entities is built-in, covering meshes, deformable meshes, a few lamps, receivers, and components of Synlight. Aside this, there's also a preview feature, which visualizes the scene setup. This combines with a visual-programming based target function editor for optimization tasks. This enables building optimization tasks using mainly domain-knowledge without first having to acquire in-depth differentiable ray tracing experience.

An image viewer for outputs, and import/export for images (CSV, PNG), meshes (Wavefront OBJ) and graphs (CSV) are also included. Program data can be stored in a project file format, and the software includes provisions for backwards compatibility. As technical foundation only permissively licensed open-source libraries (such as Intel Embree as raytracing-kernel) are used to ensure legal compatibility for many use cases.

POTENTIAL APPLICATIONS

There are many potential applications for the software. Among others, these could include:

- Reconstruction of solar simulator deformations, such as macroscopic shape of reflectors, by using per-pixel gradients
- Design and preparation of experiments for solar research facilities
- Simulation and geometry optimizations of solar-based reactors using gradients of cavity geometry
- Geometry optimizations of glass panes and mirrors for achieving even flux distributions

Due to the amount of flexibility offered by the software, this is by no means a complete list, and we are eager to learn about new application ideas.

VALIDATION

The software was initially validated by reconstructing flux measurements of deformed reflectors in the Synlight solar simulator in Juelich. This yielded a mean absolute error percentage of 0.5% to 2% in the majority of cases, indicating that it is possible to simulate real situations using the software. Further validations with other light sources (artificial and natural) or/and optical devices will follow soon.

COMMUNITY ENGAGEMENT

The novel method was introduced at the SolarPaces conference in 2024 and has received a wide interest among operators of CSP-related research facilities, solar simulators and solar furnaces. It will be intensively used for test rig design, reactor or receiver modelling. Furthermore, the software will soon be used in a collaborative project to design a solar simulator for socio-psychological experiments. For this it will be constantly updated by the Institute of Future Fuels and by national and international partners. An open-source access to the libraries will enable the transnational collaboration together with the strong need for reliable and affordable solutions for flux modelling.

REFERENCES

Pargmann, M. et. al., (2018), ARTIST, URL: https://github.com/ARTIST-Association/ARTIST

Ahlbrink, N. et al, (2012), STRAL: Fast Ray Tracing Software With Tool Coupling Capabilities for High-Precision Simulations of Solar Thermal Power Plants. Proceedings of the SolarPACES 2012 conference.

Homan Igehy (1999), Tracing ray differentials. In Proceedings of the 26th annual conference on Computer graphics and interactive techniques (SIGGRAPH '99).

CONFERENCE TOPIC

Conference topic related: 2.02. IT Solutions and Artificial Intelligence

IMPROVED OVERHEATING CONTROL STRATEGY IN FLAT PLATE COLLECTOR SOLAR THERMAL PLANT FOR SHIP APPLICATION

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Conference Topics: Net-zero/negative Emissions in the Industry including CCUS - Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications

Key Worlds: Overheating, Solar heat, Flat Plate collector, Advanced control strategy

SUMMARY

Flat plate collectors accounts for an important part of all large scale solar thermal plant word wide. However, they tend to be at risk of overheating when the heat sink is insufficient or the weather conditions are too extreme. This paper aims to explore and compare different overheating handling strategies to ensure a reliable, safe and maximum heat production. A numeric parametric study is conducted on a state-of-the-art existing thermal plant in Verdun (France), to assess the impact of each control variable on the overall performances. The temperature at the bottom of the storage tank and the setpoint temperature at the outlet of the solar field are identified as key variables. The use of a dry cooler to dissipate surplus heat offers more freedom and safety in the plant operations, at the cost of an increased electrical consumption. Its appropriate activation is highly dependent on the weather conditions and consumer's load.

INTRODUCTION

Heat accounts for more than half of the primary energy need in Europe, and this figure rise even higher considering the industrial sector alone. Solar Heat for Industrial Processes (SHIP) is a promising solution for its decarbonation. SHIP plants need to address safely the requirement of their industrial consumer, often at varying load and/or temperature level, at all time and under any operating conditions. The risk of overheating arises when the heat sink (i.e. consumer) does not sufficiently cool the heat-transfer fluid, leading to an increase of inlet temperature in the collectors and therefore an increase of the outlet temperature. An overly high outlet temperature can lead to damage in some part of the system (such as plastic components). In addition, solar flat plate collectors, which are expected to become the leading collector's technology in the following years, are particularly vulnerable to overheating when not coupled with a sun tracking device. To tackle this issue, several methods aiming to protect the plant against overheating have been tested in both literature and industry, mostly regarding the design of the collectors and the materials used in their constitution. However, as mentioned in (Quiles, Aguilar and Aledo, 2014), most solar thermal system can still be vulnerable to overheating and stagnation even if this issue was anticipated in the design stage, highlighting the need of adequate and proactive overheating control. Hence, this study aims **to provide a comprehensive** description and comparison of overheating control strategies in large scale solar plant, thanks to a numerical parametric study conducted on an existing installation.

LACTOSOL A BEST-PRACTICE INDUSTRIAL STUDY CASE

The LACTOSOL solar plant is chosen as a case study, since according the IEA (IEA SHC Task 49, 2015) it possesses some of the most advanced features regarding overheating handling in industry. **LACTOSOL, located** in Verdun (France), has been built and is operated by the French company NEWHEAT. It features almost 15000 square meters of flat plate collectors coupled via a heat exchanger to a 3000 cubic meter water tank used as sensible heat storage. The plant delivers heat to a food processing factory, with varying thermal load at a temperature range below 100°C. Due to the design of this plant and the nature of the heat transfer fluid in the solar loop (water-glycol), the temperature at any point in the solar field should never exceed 110°C, as it would greatly endanger the plant integrity. A dry cooler is installed at the output of the solar field to cool down the heat transfer fluid. It is used in two operating modes called "Day Cooling" (DC) and "Night Cooling" (NC). In DC, a certain share of the mass flow is diverted from its normal circuit to the dry cooler, reducing therefore the solar field inlet temperature while maintaining production. In NC, the storage is discharged through the solar field to reduce the state of charge. The fluid is cooled by passive circulation in the solar loop, and if necessary, the dry cooler can be activated to achieve a specified return temperature. The following cooling mode are used in a preventive overheating handling strategy, aiming to limit the bottom storage temperature, to ultimately reduce the solar field inlet temperature. Therefore, their activation depends on whether or not a certain layer of the storage exceeds a critical temperature. The considered layer and temperature are the main control variables regarding the cooling strategy. The NC activation is also time dependent, as it can only be used after a specified controlled hour. The setpoint of the solar field outlet temperature is the principal control variable when the plant operates under standard conditions, however it also greatly impacts the overheating handling strategy.

METHODS AND RESULTS

In order to evaluate which combination of the cooling modes allows for an efficient, safe and reliable control, a parametric study is conducted on all of the previously mentioned variable. The dynamic behaviour of the system is described by a Dymola model developed by the plant operators, using weather and thermal load data issued from onsite measurement. This model as well as a yearly historic of its input data is encompassed in a functional mock up unit (FMU), which is then simulated in a Python environment thanks to the FMPy Library. To reduce computational time, three characteristic four-day periods were selected to represent the entire period during which overheating may occur. They were chosen to ensure a comprehensive representation of variations in external conditions (solar irradiance and thermal load). A series of hourly simulation is performed to assess the impact of a control variable on the plant overall performances, for each period. An emphasis is put on maximising the heat production while ensuring the system remains within its design temperature range (<110°C). The energy consumption of the cooling strategy (dry cooler and circulation pump) is also assed. The preliminary results highlight the importance of passive cooling to efficiently cool down the plant, while limiting auxiliary's electric consumption as the use of the dry cooler can almost double the operating cost. The solar field output temperature setpoint, is identified to be a key control variable thanks to its direct impact on the thermal stratification the tank and on the supplied heat temperatures. The plant performs better at high temperature therefore a rise of 10°C of the setpoint can increase the profit up to 7% during a characteristic period. The overall overheating handling strategy performances are highly dependent on the operating condition, especially the possible stop and restart of the consumer's thermal load. The NC seems to be more effective for most of the operating conditions, the exception being if a restart in production occurs during the night or in the morning while the state of charge is at its lowest.

REFERENCES

IEA SHC, Overheating and Stagnation (2015). Available at: https://www.iea-shc.org/Data/Sites/1/publications/IEA%20Task%2049_Deliverable%20A1_Frank_OverheatingStagnationReport_approved_v-2-3.pdf.
Quiles, P.V., Aguilar, F.J. and Aledo, S. (2014), Analysis of the Overheating and Stagnation Problems of Solar Thermal Installations, *Energy Procedia*, 48, pp. 172–180. Available at: https://doi.org/10.1016/j.egypro.2014.02.022.

INSIGHTS FROM CONCEPT DEVELOPEMENT – SMART STORAGE SOLUTIONS FOR THE FUTURE OF URBAN ENERGY SYSTEMS

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SUMMARY

This contribution explores innovative thermal energy storage (TES) solutions as a cornerstone for achieving sustainable urban heating and cooling systems. By integrating seasonal, short- and medium-term storage technologies into district and local heating networks, mismatches between renewable heat supply and demand can be mitigated. Different building structures (new construction vs. existing stock) and uses (residential vs. commercial) create highly diverse requirements for storage integration. While some technologies such as buffer tanks for short-term balancing and borehole fields for seasonal storage are already in use, they do not cover the full range of urban needs. Therefore, additional concepts and approaches are required to address the variety of local conditions. The contribution provides an overview of TES approaches, examples from different application contexts, and general insights into their potential roles within future energy systems.
Keywords: thermal energy storage, district heating, renewable energy, urban energy systems, decarbonization

INTRODUCTION

One of the key challenges for urban energy transitions is the provision of 100% renewable heating under very different framework conditions. In Vienna, 45% of the heat demand in 2021 was still covered by fossil fuels and 34% by district heating, largely based on natural gas and waste incineration. To reach full decarbonization by 2040, innovative renewable heating solutions are required, with a strong role for local district and neighborhood heating systems. New buildings allow for integrated planning, while existing stock requires retrofitting within tight technical and economic limits. In particular, limited space availability in existing buildings can make the integration of storage solutions challenging. Similarly, residential and commercial buildings differ in demand patterns, peak loads, and operational strategies.

Thermal energy storage is central to overcoming these challenges, enabling temporal and spatial balancing of supply and demand as well as increasing system flexibility and resilience. Technologies such as buffer tanks and borehole fields already demonstrate the potential of storage, but their suitability is strongly shaped by local demand conditions, space availability, and system configuration. To achieve sustainable cities, a broader portfolio of TES technologies must be explored and adapted.

PROJECT OBJECTIVES AND CONTENT

The contribution illustrates how thermal energy storage requirements vary significantly across different building types and uses. It shows the distinct role TES can play in both new construction, where integration can be planned from the outset, and in existing buildings, where retrofitting is often limited by space and technical constraints. Examples are provided to demonstrate the application of both established and emerging storage technologies, highlighting how solutions can differ depending on building density, local demand patterns, and system configuration. Instead of a one-size-fits-all approach, the contribution emphasizes the importance of matching suitable storage concepts to the specific urban context and to different storage horizons ranging from short- to long-term.

INNOVATION AND IMPACT

The innovative aspect lies in differentiating TES applications according to building and usage contexts, rather than treating storage as a one-size-fits-all solution. By moving beyond technologies that are already commonly applied, further options can be identified and assessed for their potential contribution.

Ecological impact: Broader deployment of TES enables higher shares of renewable heat, reductions in CO_2 emissions, and improved resilience against climate extremes.

Economic impact: More precise technology selection avoids oversizing, optimizes investment costs, and tailors solutions to diverse urban needs.

CONCLUSION

This contribution provides insights into how thermal energy storage can be adapted to the varying requirements of urban buildings and uses. By expanding the technology spectrum beyond commonly applied concepts and aligning storage solutions with different building contexts, TES can play a decisive role in achieving sustainable heating, thereby also contributing significantly to meeting the climate targets for 2040. These findings are relevant not only for Vienna but also for other cities aiming to accelerate the transition towards renewable and resilient urban energy systems.

REFERENCES

Köfinger, M., Basciotti, D., Lager, D., Terreros, O., Zauner, C., Böhm, H., Lindorfer, J., Tichler, R., & Zauner, A. (2018). SeasonalGridStorage - Innovative saisonale Wärmespeicher für urbane Wärmenetze: Konzepte zur Nutzung thermochemischer Speicher. Schriftenreihe 21/2018. Herausgeber: BMIT. Accessed on August 25, 2025, from https://nachhaltigwirtschaften.at/resources/sdz_pdf/berichte/schriftenreihe-2018-21-sgs.pdf

Schädle, K.-H., Schmidt, T., Berberich, M., Arndt, D., Klingler, P., & Co-Autoren. (2018). Einsatz von thermischen (saisonalen) Speichern in thermischen Netzen. Schlussbericht, 9. Februar 2018, Programm „Thermische Netze“. Herausgeber: BFE. Accessed on August 24, 2025, from https://pubdb.bfe.admin.ch/de/publication/download/9015

Stadt Wien. (2022). Energieeffizienz und Anwendungen: Wärme. Accessed on August 26, 2025, from https://www.wien.gv.at/spezial/energiebericht/energieeffizienz-und-anwendungen/warme/

Stadt Wien. (2024). Wiener Wärmeplan 2040. Accessed on August 24, 2025, from https://www.wien.gv.at/umwelt/waermeplan-2040

Suna, D., García, N. P., Totschnig, G., Wimmeder, S., Meißner, E., Ungerböck, R., Graf, A., Dornhofer, A., & Niederkofler, M. (2022). Sondierung des wesentlichen F&E-Bedarfs zur Optimierung von städtischen Energiespeichern in integrierten Energiesystemen (CityStore). Schriftenreihe 4/2022. Herausgeber: BMK. https://nachhaltigwirtschaften.at/resources/sdz_pdf/schriftenreihe-2022-4-citystore.pdf

CONFERENCE TOPIC

1.08. Future District Heating and Cooling Solutions

1.12. Next-Generation Technologies for Renewable Energy and Resource Efficiency

1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

LONG-TERM DISTRICT HEATING CAPACITY EXPANSION UNDER POLICY AND PRICE UNCERTAINTY

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SUMMARY

District heating (DH) systems are central to Europe's decarbonisation pathway, yet long-term capacity expansion planning faces deep uncertainties in demand, fuel prices, and evolving policy targets. This work develops and applies a multistage stochastic optimisation framework with risk measures to support robust DH planning. Using Stockholm's district heating system as a case study, the model captures sequential investment and operational decisions, incorporates policy uncertainty and thermal storage, and employs Conditional Value-at-Risk (CVaR) to evaluate the trade-off between expected costs and downside risk. The analysis will examine technology mixes under varying policy and market conditions, investment timing under extreme scenarios, and the role of risk aversion in shaping capacity pathways. Results will provide insights for municipalities and utilities in developing risk-aware, resilient heating and cooling plans.

Keywords: District heating, capacity expansion, decarbonisation, stochastic optimisation, policy uncertainty, SDDP.

INTRODUCTION

District heating (DH) systems are expected to play a major role in decarbonising urban energy supply. The EU now mandates local heating and cooling plans for municipalities, with specific annual targets to increase the share of renewable and excess heat. Planning long-term DH expansion is, however, challenged by multiple uncertainties: future heat demand, energy price trajectories, technology lifetimes, and policy developments such as carbon pricing or renewable integration requirements. Beyond uncertainty in expectations, decision-makers are also concerned with exposure to extreme outcomes, which requires explicit treatment of risk in the planning framework.

Stockholm, one of Europe's largest DH systems, represents a relevant case for studying robust and risk-aware investment strategies. This study, therefore, extends a multistage stochastic optimisation framework by incorporating policy uncertainty, thermal storage, and CVaR-based risk measures, enabling a comprehensive analysis of how risk preferences, in addition to uncertainty, shape optimal capacity expansion pathways.

METHODOLOGY

We build on a previously developed multistage stochastic optimisation framework of (Kök, Hachez and Kranzl, 2025) and extend it to reflect the specific requirements of Stockholm's DH system. The model is implemented in Julia using SDDP.jl (Dowson and Kapelevich, 2021), which solves large-scale stochastic dual dynamic programming problems.
The planning horizon spans from 2025 to 2050, divided into investment stages (every 5 or 10 years) followed by operational stages. Investment decisions include capacity additions for candidate technologies such as large-scale

heat pumps, combined heat and power (CHP) plants, boilers, and thermal energy storage. Each investment is subject to construction lead times and technology-specific lifetimes. Operational stages resolve dispatch decisions at an hourly level, using reduced typical load hours to ensure tractability.

Uncertainty is represented by: (i) demand evolution modelled as a discrete-time Markov chain with three states (growth, stable, decline), (ii) natural gas and electricity prices modelled as random variables from empirical distributions, and (iii) policy uncertainty (i.e., alternative carbon price trajectories and renewable/excess heat obligations). The model introduces a salvage value for assets that extend beyond the horizon, preventing underestimation of long-lived investments.

This study extends the objective by including a risk measure (Conditional Value-at-Risk, CVaR). Instead of focusing only on the average expected system cost, the model can also account for unfavourable outcomes such as high fuel prices or sharp demand changes. CVaR allows exploring how more risk-averse strategies would change investment choices. By adjusting the level of risk aversion, we can analyse the trade-off between keeping expected costs low and protecting the system against extreme but plausible scenarios.

Thermal storage is explicitly represented to assess its role in smoothing demand fluctuations and improving system flexibility. The policy graph approach in SDDP allows the model to represent multiple uncertain processes without exploding the scenario tree. This ensures computational tractability while maintaining fidelity in the representation of uncertainty.

EXPECTED RESULTS

The Stockholm case study will analyse alternative investment pathways under combined demand, price, and policy uncertainties, with a particular focus on investment sequencing. We will examine which technology mixes are favourable under different policy ambitions and market conditions, how TES interacts with other technologies, and under what conditions each option becomes competitive or is phased down.

We will investigate rare/extreme scenarios (e.g., prolonged low gas prices, accelerated demand reductions, or high carbon prices) to assess their effects on investment timing, stranded-asset risk, and system robustness. Using the CVaR-based formulation, we will quantify how risk aversion shifts decisions and identify investment pathways that reduce exposure to high-cost realisations. Comparative analyses against risk-neutral, deterministic, and two-stage formulations will highlight how uncertainty and risk preferences influence technology uptake, emissions trajectories, and lifecycle system costs.

CONCLUSIONS

This study demonstrates how risk-aware multistage stochastic optimisation informs investment decisions for long-term DH expansion under policy and market uncertainty. By integrating CVaR in a nested, time-consistent manner and explicitly modelling TES and policy scenarios, the framework reveals how risk preferences alter investment sequencing and technology choice, providing decision-makers with evidence-based trade-offs between expected cost and downside protection. The Stockholm application will deliver policy-relevant guidance for robust heating and cooling plans aligned with EU decarbonisation goals and support strategic planning for large DH systems facing deep uncertainty.

REFERENCES

Dowson, O. and Kapelevich, L. (2021) “SDDP.jl : A Julia Package for Stochastic Dual Dynamic Programming,” *INFORMS Journal on Computing*, 33(1), pp. 27–33. Available at: https://doi.org/10.1287/ijoc.2020.0987.

Kök, A., Hachez, J. and Kranzl, L. (2025) “A Multistage Stochastic Optimization Framework for Long-Term District Heating Capacity Expansion,” in *2025 21st International Conference on the European Energy Market*

(EEM). *2025 21st International Conference on the European Energy Market (EEM)*, Lisbon, Portugal: IEEE, pp. 1–8. Available at: https://doi.org/10.1109/EEM64765.2025.11050152.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

- 1.08. Future District Heating and Cooling Solutions
- 1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

CIRCULAR ECONOMY FOR HEAT PUMPS – STATUS, APPROACHES, POTENTIAL – IEA HPT ANNEX 65

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SUMMARY

Heat Pumps are central and crucial technology to reach a sustainable transformation of the heating sector, both in domestic buildings and in industrial heat supply. The technology gains more and more interest and a significant growth of sales numbers can be seen over the years, coming along with further growth rates over the coming years and decades. The market growth comes along with increasing resource needs for Heat Pumps. Therefore, the assessment and optimization of resource use, resource efficiency and – as a summarizing term – circular economy of heat pumps becomes important for a sustainable market growth. In circular Economy assessments ecological and economic aspects must be addressed. The Heat Pump Program (HPT) of the International Energy Agency (IEA) took these topics up and started a dedicated activity: Annex 65 "Heat Pumps in a Circular Economy". The paper reports on activities within the Annex, as well as first results and outcomes.

INTRODUCTION

The IEA estimates in the recent Net Zero Roadmap that the global heat pump stock in capacity will triple from 1,000 GW to 3,000 GW [1] as heat pumps are considered a key technology in the decarbonization of space heating [2]. This is likely to result in a large deployment of heat pumps, which means that the material footprint of heat pumps will increase significantly in the coming years.
Like most technical installations, heat pumps consist of materials with a significant material footprint. To align this with a circular economy, the products need to be optimized in a lifecycle perspective with a long lifetime and with the possibility for lifetime extension through repairs. The requirements and the associated documentation are expected to increase in the coming years as the carbon footprint in all use phases becomes a competitive parameter. This is already happening in some markets where limits are introduced on building level to restrict the lifecycle carbon footprint of buildings.
This means that companies providing individual heat pumps for space heating need to adjust their products to accommodate a future where both energy and material efficiency are important competitive parameters.

METHODOLOGY

To ensure cost-effectiveness and competitiveness in the transition to a circular economy the heat pump industry needs to have access to a forum where knowledge is collected and shared. And this is the overall objective of the Annex, which will provide an overview of the status of heat pumps in relation to a circular economy, highlight the technological possibilities for improving the circularity as well as develop best practice recommendations. In practice, an overview of the terminology for material efficiency must be created as well as a literature study of relevant topics related to circular economy. The current state-of-the-art for circular economy for domestic heat pumps needs to be defined, and the potentials for circular economy and potential barriers to recycling and dismantling need to be assessed. Finally, best practice tools must be developed to achieve an improved material efficiency in domestic heat pumps, and the results of the work will be communicated to relevant stakeholders.

The work in the Annex is structured in activities:

- Task 1: Definitions and delimitation – Determine definitions and set a framework for working with circular economy in heat pumps
- Task 2: State-of-the-art – Collect information on national and international initiatives on material efficiency and circular economy
- Task 3: Evaluation of potential – Evaluate the potential for circular economy and potential obstacles for reusing and dismantling
- Task 4: Guideline development – Develop design and dismantling guidelines
- Task 5: Dissemination

RESULTS

The work of Task 1 has been focusing on the following topics:
Task 1.1 Evaluating material efficiency standards
Task 1.2 Reviewing relevant regulations
Task 1.3 Analyzing lifecycle impacts.
Task 1.4 Presenting case studies on circular design measures:.

Key findings were:
- The shift to a circular economy presents both challenges and opportunities for the heat pump sector. While circular principles can drive innovation and sustainability, they also require significant adaptation of existing standards, regulations, and design practices.
- Current circular economy standards, such as the ISO 59000 family and the EN 4555X series, need further adaptation to address the specific requirements of heat pumps. These standards, while generic, provide a foundation for developing product-specific guidelines to improve material efficiency and circularity. Developing product-specific standards is critical to enabling practical implementation.
- Regulatory frameworks like Ecodesign and REACH are increasingly pushing for sustainability through material efficiency, durability, and recyclability requirements. However, these regulations also create challenges, such as the potential impact of PFAS restrictions on material availability and product performance.
- A lifecycle analysis performed by RWTH Aachen confirms that air-to-water heat pumps in the German scenario reduce greenhouse gas emissions compared to conventional systems (gas boiler). However, the study also highlights the importance of also paying attention to the environmental impacts linked to the production and end-of-life phases in order to minimize the risk of burden-shifting.
- Collaboration within the industry is essential to harmonize lifecycle data, develop product-specific standards, and align with circular economy principles. For instance, the lack of harmonized Product Category Rules (PCRs) for heat pumps currently limits the comparability of Environmental Product Declarations (EPDs).

The paper will present an overview on the activities of the Annex with special focus on the results of Task 1 and Task 2 “State of the Art” which will also be completed by the full paper deadline.

REFERENCES

[1] IEA (2023), Space heating, IEA, Paris https://www.iea.org/reports/space-heating, License: CC BY 4.0
[2] IEA (2022), The Future of Heat Pumps, IEA, Paris https://www.iea.org/reports/the-future-of-heat-pumps, License: CC BY 4.0

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CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

- 1.03. Circular Economy Strategies for the Energy Transition

EXPERIMENTAL STUDY AND MODELING OF SORPTION-ENHANCED SMR USING NI/CAO–MAYENITE COMBINED MATERIAL

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SUMMARY

Hydrogen (H_2) has emerged as a promising clean energy alternative for various industrial applications, although current production pathways remain largely unsustainable. Sorption-enhanced steam methane reforming (SE-SMR) addresses carbon mitigation targets by integrating in situ CO_2 capture through solid sorbents, thereby enhancing feedstock conversion and H_2 purity, and enabling compact reactor configurations under moderate operating conditions. Combined sorbent–catalyst materials (CSCMs), which integrate Ni-based reforming catalysts with CaO-based sorbents and inert stabilizers such as mayenite, are synthesized to prevent sorbent sintering and catalyst deactivation during cyclic operations. Experimental results confirm the cyclic stability of Ni–CaO–mayenite CSCMs and validate Aspen Plus simulations. The SE-SMR process model, that further incorporates a Pressure Swing Adsorption unit to achieve 99% H_2 purity, demonstrates over 70% of conversion efficiency and 90% of CO_2 capture rate, and a levelized cost of hydrogen competitive with current market prices.

Keywords: *Sorption-enhanced steam methane reforming, Combined sorbent–catalyst materials, carbon mitigation, levelized cost of hydrogen*

ABSTRACT

Growing awareness of greenhouse gas emissions resulting from the extensive use of fossil fuels has highlighted the need to develop clean energy technologies to ensure a sustainable future. In this context, hydrogen has emerged as one of the most promising alternatives with widespread applications in industry, transport, energy production, petroleum refining, and the manufacture of chemicals such as ammonia and methanol [1]. Currently, steam methane reforming (SMR) is the most widely employed method for hydrogen production due to its favourable economics, although its environmental impact remains a major concern, with approximately 10 tons of CO_2 emitted per ton of hydrogen produced [2]. To meet carbon mitigation targets, SMR must be integrated with CO_2 capture technologies, while ensuring that hydrogen production remains economically competitive. To this aim, an appealing option is the Sorption-Enhanced Steam Methane Reforming (SE-SMR), which evolves the SMR by integrating in situ CO_2 capture via carbonation on a solid sorbent such as CaO. The presence of this sorbent in the reformer enhances feedstock conversion according to Le Chatelier's principle, thus increasing hydrogen purity without the need for additional Water-Gas Shift (WGS) reactors and enabling operation at lower reforming temperatures than the conventional process. Once the sorbent is saturated, it can be regenerated through calcination at high temperature, producing high purity CO_2. However, the implementation of SE-SMR is challenged by the CO_2 uptake capacity over progressive carbonation/calcination cycles due to sintering and by the performance of the catalyst under the SE-SMR reaction environment. To address these issues, we synthesize combined sorbent–catalyst materials (CSCMs) for SE-SMR, incorporating both the catalytic phase for SMR and the sorbent phase for CO_2 capture. Notably, Ni is commonly employed as the SMR catalyst for economic reasons, whereas CaO-based sorbents including inert stabilizers like mayenite ($Ca_{12}Al_{14}O_{33}$) represent a well-established

strategy to mitigate sintering, while also offering high CO_2 sorption capacity and fast carbonation kinetics within the temperature range of reforming reactions, i.e. 600-650 °C, together with suitable regenerability by calcination at 800–1100 °C. In this context, CaO–mayenite sorbents combined with Ni-based reforming catalysts are selected to synthesize CSCMs [3], [4], [5], [6], [7]. Specifically, sorbent synthesis involves preparing CaO supported mayenite using a scalable sol-gel method followed by mixing, granulating, and testing the two calcined powders. Sorbent is impregnated with a solution of $Ni(NO_3)_2 \cdot 6H_2O$, then dried in an oven at 120°C for one night and subsequently subjected to a second calcination step at 850°C for 5 hours.

Based on the SE-SMR experimental outcomes, the reaction kinetics and optimal operating conditions are determined and integrated within Aspen Plus simulations. Figure 1 shows a schematic representation of process model, including a Pressure Swing Adsorption (PSA) unit is included downstream of the reformer to achieve a hydrogen purity of 99%. An economic assessment is then carried out on the basis of the modelling results, enabling the estimation of the levelized cost of hydrogen (LCOH) and its competitiveness within the current hydrogen market.

The synthesized Ni–CaO–mayenite CSCMs exhibit anti-sintering properties by remaining active and stable for more cycles. Specifically, sorbent performance are evaluated using a plug-flow reactor integrated on a SE-SMR test rig (Micromeritics FR-100) and fed by methane and steam at both atmospheric pressure and 8 bar. Sorbent regeneration is performed at atmospheric pressure. Modelling of SE-SMR plant on Aspen Plus shows good agreement with the experimental data, thus confirming the validation of the simulation outcomes. Based on such results, the SE-SMR plant achieves a conversion efficiency exceeding 70%, while simultaneously enabling a CO_2 capture rate higher than 90%. Finally, the SE-SMR plant exhibits a LCOH that is competitive within the current hydrogen market. Indeed, while conventional grey hydrogen production processes, including SMR, partial oxidation, and autothermal reforming, typically have an LCOH less than half of that obtained in this study, green hydrogen generally costs up to three times this figure [8].

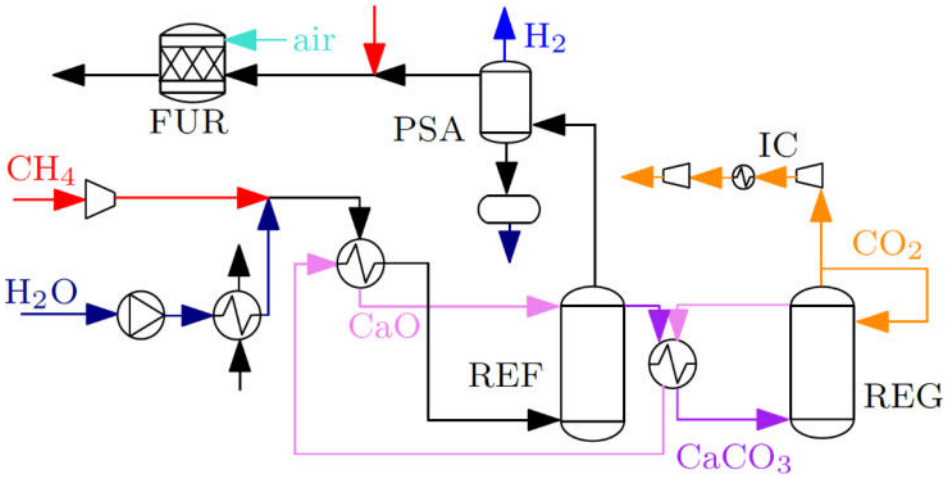


Fig. 1: Schematic representation of the SE-SMR plant. Shown are REF the reformer, PSA the Pressure Swing Adsorption unit, REG the regenerator, IC the intercooled multi-stage compression, and FUR the furnace.

REFERENCES

[1] B. C. Tashie-Lewis and S. G. Nnabuife, "Hydrogen Production, Distribution, Storage and Power Conversion in a Hydrogen Economy - A Technology Review," *Chemical Engineering Journal Advances*, vol. 8, Nov. 2021, doi: 10.1016/J.CEJA.2021.100172.

[2] N. Muradov, "Low to near-zero CO2 production of hydrogen from fossil fuels: Status and perspectives," *Int J Hydrogen Energy*, vol. 42, no. 20, pp. 14058–14088, May 2017, doi: 10.1016/J.IJHYDENE.2017.04.101.

[3] A. Di Giuliano, K. Gallucci, A. Di Carlo, S. Stendardo, C. Courson, and P. U. Foscolo, "Sorption enhanced steam methane reforming by Ni/CaO/mayenite combined systems: Overview of experimental results from European

research project ASCENT," *Can J Chem Eng*, vol. 98, no. 9, pp. 1907–1923, Sep. 2020, doi: 10.1002/CJCE.23779.

[4] A. S. Farooqi *et al.*, "Performance of Ni-M/Ca12Al14O33 (M= Co, Cu and Fe) bimetallic catalysts in sorption-enhanced steam methane reforming for blue hydrogen production," *Catal Today*, vol. 454, p. 115281, Jun. 2025, doi: 10.1016/J.CATTOD.2025.115281.

[5] A. Di Giuliano, J. Girr, R. Massacesi, K. Gallucci, and C. Courson, "Sorption enhanced steam methane reforming by Ni–CaO materials supported on mayenite," *Int J Hydrogen Energy*, vol. 42, no. 19, pp. 13661–13680, May 2017, doi: 10.1016/J.IJHYDENE.2016.11.198.

[6] A. Caroline Pereira Oliveira, D. Bruno Lima Santos, L. Gomes Moura, and C. Eponina Hori, "Sorption-enhanced steam reforming of propane using bifunctional Ni/CaO, Ni/CaO-CaZrO3, and Ni/CaO-Ca2SiO4 catalysts," *Fuel*, vol. 358, p. 130170, Feb. 2024, doi: 10.1016/J.FUEL.2023.130170.

[7] "Marion Technologies." Accessed: Sep. 09, 2025. [Online]. Available: https://www.mariontechnologies.com/en/home/

[8] J. M. M. Arcos and D. M. F. Santos, "The Hydrogen Color Spectrum: Techno-Economic Analysis of the Available Technologies for Hydrogen Production," *Gases 2023, Vol. 3, Pages 25-46*, vol. 3, no. 1, pp. 25–46, Feb. 2023, doi: 10.3390/GASES3010002.

CONFERENCE TOPIC

1.11 Net-zero/ negative Emissions in the Industry including CCUS

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ADVANCING GENDER EQUALITY IN RENEWABLE HEATING AND COOLING SECTOR: LESSONS FROM SOLTRAIN+ WP5 ONLINE SERIES

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SUMMARY

Achieving a just and inclusive energy transition requires tackling barriers that limit women and youth participation in the renewable heating and cooling (RHC) sector. To address barriers such as limited access to finance, underrepresentation in technical careers, and lack of mentorship, SOLTRAIN+ gender and diversity launched an online meet-up series in 2024, coordinated by national gender managers. Between July 2024 and July 2025, ten sessions engaged over 200 participants, followed by an Action-Point Dialogue to consolidate outcomes.

Key priorities identified included; mentorship programmes, gender-sensitive training, targeted financing schemes, inclusive workplace practices, and stronger peer-to-peer platforms. The series demonstrates that sustained dialogue, mentorship, and organisational support are essential to advancing inclusivity in the RHC sector, offering lessons that will inform the final phase of SOLTRAIN+and contribute to broader efforts for a just and inclusive energy transition.The action-point dialogue underscores the importance of integrating gender-responsive training and improving access to finance as central measures for advancing equality in the sector.

INTRODUCTION AND BACKGROUND

The Southern African Solar Thermal Training and Demonstration Initiative (SOLTRAIN+) (2023–2026), funded by the Austrian Development Agency, is implemented by SACREEE with AEE INTEC. It promotes renewable heating and cooling solutions in Botswana, Lesotho, Namibia, South Africa, and Zimbabwe through technology demonstration, training, and awareness. The project also prioritises gender and diversity to boost women's and youth participation in the energy sector.

The renewable heating and cooling (RHC) sector in the SADC region continues to face gender gaps that limit the participation of women, youth, and other underrepresented groups. A situational analysis conducted in 2023 revealed key gender gaps in the RHC sector: limited access to finance, underrepresentation in technical careers, and lack of mentorship structures. To address these, SOLTRAIN+ launched a continuous online meet-up series in 2024, coordinated by national gender managers, to promote dialogue, knowledge exchange, and capacity building.

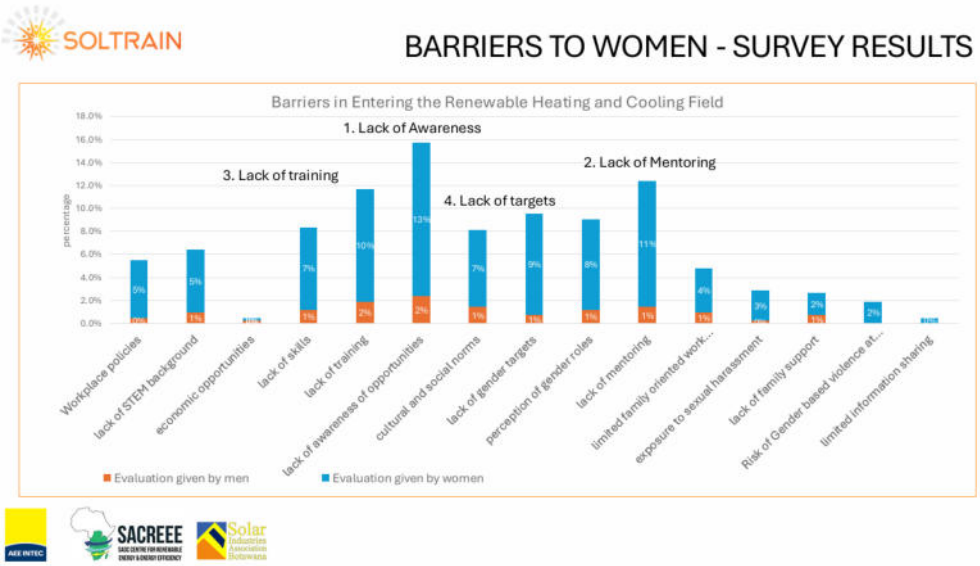


Figure 1 : Barriers to Women - 2023 Survey Results (SOLTRAIN+)

METHODOLOGY

The meet-up series is designed as a monthly, interactive platform convened by the SOLTRAIN+ Gender and Diversity team, facilitated by the project's national gender managers (GM). The GMs selected the themes to be discussed in consultation with the survey results.Gender managers were upskilled in presenting, moderating, and leading discussions.

The meet-up sessions targeted women professionals, students, and gender multipliers who were reached through LinkedIn, the SOLTRAIN website, and project mailing lists.The session themes included financial literacy, women's entrepreneurship, inclusive workplace practices, and the role of men as allies.

RESULTS

Between July 2024 and July 2025, ten meet-up sessions were successfully conducted, with over 200 participants joining across the region. These sessions highlighted persistent barriers such as limited access to finance, lack of mentorship, and gender-insensitive training frameworks, while also identifying enablers such as peer-to-peer knowledge sharing, gender-responsive policies, and embedding mentorship into project structures.

The eleventh (11) session, held as an Action-Point Dialogue, consolidated the outcomes of the first ten sessions and gathered participant input on priority measures to advance gender equality in the RHC sector.

Topic	Date	Gender Manager
1. How to increase RHC training accessibility to under privileged women & girls: possible avenues	23.07.2024	Jenny Chigewera
2. As beacons or voices advancing for gender equality in perceived male dominant professions ,advocating for the female increment in the energy sector, how do we maintain them?'.	20.08.2024	Tawha Peter
3. Professional Associations	24.09.2024	Reabetseo
4.How to I introduce these (energy) topics to young girls at school level	29.10.2024	Simnikiwe
5. How can men in the energy sector advance gender equality	28.01.2025	Malitha
6. How to empower women without making men feel left out	25.03.2025	Asteria Markus
7. Financial Literacy and Access to Capital for Women in RE	25.04.2025	Tawha Peter
8. Improvement of energy efficiency for economic development at Penduka women centre in Windhoek	27.05.2025	Hendrina Shinime
9. How to succeed in male dominated industries - the female factor	26.06.2025	Welcome Nukiri
10. How to increase the attractiveness of RHC technical Jobs to Women & Youth	29.07.2025	Monika Spoerk Dur

Figure 2: SOLTRAIN+ WP5 Online Meet-Up Sessions (2024–2025) (SOLTRIAN+)

DISCUSSION OUTCOMES AND RECOMMENDATIONS FOR FURTHER ACTIONS

During the 11th Action-Point Dialogue, gender managers and participants agreed on several priorities to advance gender equality in the renewable heating and cooling sector. They highlighted the need for structured mentorship programmes and professional associations for women to strengthen networks, as well as integrating gender-sensitive curricula in technical institutions and offering tailored training for women entrepreneurs.

Access to finance was emphasised through the development of targeted schemes for women- and youth-led enterprises, complemented by financial literacy and business development support. Participants also stressed the importance of mainstreaming gender in energy policies, promoting inclusive workplace practices, and strengthening peer-to-peer platforms.

The series demonstrates that gender mainstreaming requires continuous dialogue, strong professional networks, awareness-raising, mentorship, and organisational support. With ten sessions completed, the lessons learned underscore the importance of integrating gender-responsive training and improving access to finance. These insights will inform the final phase of SOLTRAIN+ and contribute to broader regional and global efforts towards a just and inclusive energy transition.

REFERENCES

1. SOLTRAIN, (2023), Home page, (https://soltrain.org/)
2. SOLTRAIN, (2023), Situational Analysis (Internal Project Document)
3. SOLTRAIN, (2024), Project Interim Report, (Internal Project Document)
4. SOLTRAIN LinkedIn page, (https://www.linkedin.com/company/soltrain-sadc/)

CONFERENCE TOPIC

2.03. Just and inclusive mechanism for the energy transition

TESTING AND DEMONSTRATION OF A RIVER WATER HEAT PUMP WITH PARTIAL FREEZING AND DISTRICT HEATING FEED-IN

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SUMMARY

Many cities and towns are located near bodies of water. Lakes, rivers, and seas often represent powerful, efficient, and cost-effective heat sources for heat pumps, even for systems with high output [1]. However, existing hydrothermal heat pump systems cannot be operated at low water temperatures because of the risk of evaporator freezing. This restricts their use precisely when heating demand is at its highest.
The triple point process is implemented in a vacuum liquid ice plant. As water freezes, it releases energy that drives the evaporation of nearby water molecules. The water vapour is compressed by a turbo compressor to a higher temperature level where it can be used in the downstream stage of the heat pump cascade. Heat extraction in the evaporator produces a pumpable water–ice mixture (liquid ice), which is returned to the water body. This allows the water body to serve as a powerful and efficient heat source even at temperatures close to freezing. At the same time, the amount of water circulating between the water body and the heat pump is significantly reduced (see Figure 1).

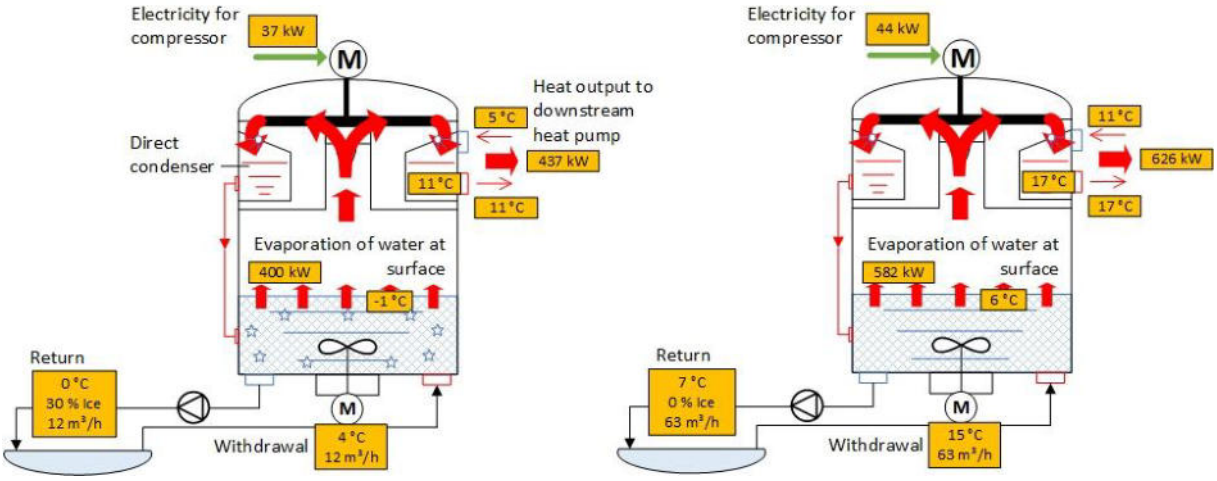


Fig. 1: Principle of heat extraction through direct evaporation or partial freezing of water in the triple-point-process, left: freezing operation (12 m³/h), right: non-freezing operation (86 m³/h)

INTRODUCTION

As part of the AQVA HEAT I project, a vacuum heat pump system was installed on the premises of Stadtwerke Zittau, and successfully tested in autumn 2022, using the Mandau River as a heat source. In addition to the technological aspects, the ecological impact on the water was also investigated [2]. However, heat feed-in and utilisation were not included in the three-month trial operation.
This step will now follow within the AQVA HEAT II and III projects. A vacuum liquid ice generator with a heat extraction capacity of 350 kW will be installed at the same location in Zittau. The second stage of the heat pump cascade is an ammonia heat pump. This transforms the heat to a temperature level of up to 95 °C, thereby achieving the flow temperature required in winter for the district heating network of Stadtwerke Zittau.



Fig. 2: Left: Direct evaporator/vacuum liquid ice generator and peripheral system components during functional testing in 2022. Right: Pumpable water-ice mixture on its way to the water body.

The plant is planned to go into operation at the end of 2025. The presentation will provide a detailed overview of the plant concept, reflecting insights from the short-term demonstration and the water law approval process.

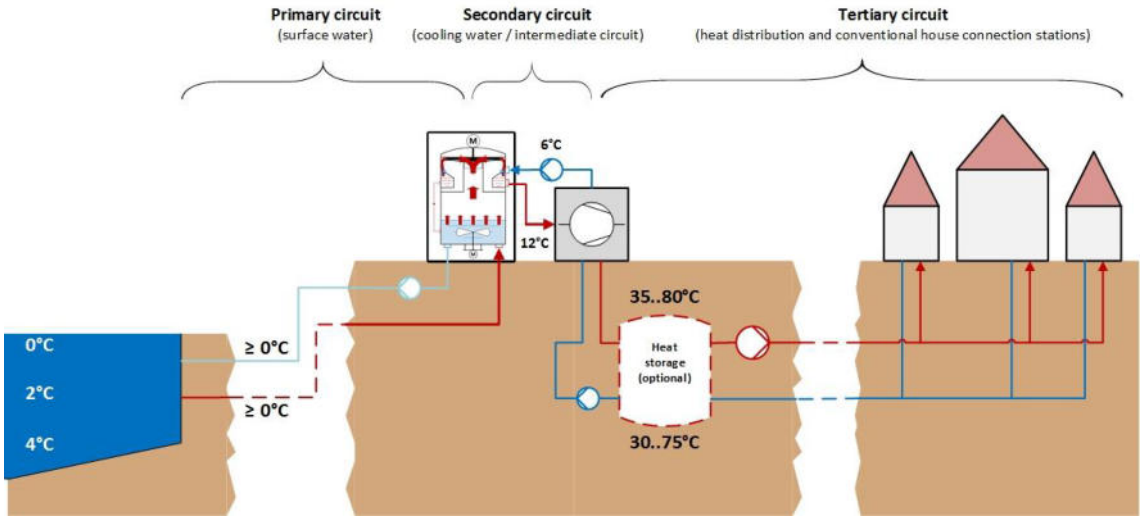


Fig. 3: Heat pump cascade consisting of a vacuum ice generator and downstream heat pump for year-round use of water bodies as a heat source

REFERENCES

[1] M. Safarik, M, Honke, B. Burandt, C. Steffan: Gewässer als Wärmequelle für Wärmepumpen großer Leistung durch Anwendung der Vakuum-Flüssigeis-Technologie. Tagungsband 23. Symposium Nutzung Regenerativer Energiequellen und Wasserstofftechnik Stralsund, 2016

[2] C. Steffan, M. Safarik, T. Gubsch, A. Kratzsch, D. Leßmann: Schlussbericht AQVA HEAT I Entwicklung und Ersterprobung eines Vakuum-Flüssigeiserzeugers zur ganzjährigen Nutzung von Oberflächengewässern als Wärmequelle. Schlussbericht zum Verbundvorhaben, Dresden, Zittau, Cottbus, 31.08.2023

CONFERENCE TOPIC

This abstract refers to the following Conference Topics:

1. Technologies and Systems for Buildings, Industry, Districts, Cities and Regions
   1.02 Building the Future: Smart Energy Infrastructure for the Energy Transition
   1.03 Coupling of Energy Sectors
   1.08 Future District Heating and Cooling Solutions

ADVANCING MECHANICAL RECYCLING OF POLYPROPYLENE: LCA INSIGHTS FROM SORTING AND WASHING STRATEGIES

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SUMMARY

European legislation increases the demand for high-quality recycled polypropylene (PP) in packaging applications in the foreseeable future. This study evaluates the influence of object-based sorting and washing intensity on material properties, product performance, and environmental impacts in mechanical recycling of Dutch post-consumer rigid PP. White, clear, and colored fractions were processed under cold and hot washing conditions, extruded, and converted into cups by injection molding and thermoforming. Sorting effectively reduced feedstock heterogeneity, while hot washing hardly improved oxidation stability and ductility. Hot washing did not significantly reduce volatile organic compounds or migration levels. Life cycle assessment confirmed that advanced recycling remains environmentally advantageous compared to virgin PP, though recyclate substitution rate in final products remained crucial. The findings indicate that maximizing substitution and sorting efficiency is more important for sustainable, high-quality PP recycling than intensive washing.

Keywords: mechanical recycling, post-consumer polypropylene waste, cold washing, hot washing, life cycle assessment, substitution rate

INTRODUCTION AND METHODS

Meeting the EU's Packaging and Packaging Waste Regulation (PPWR) targets (European Parliament and the Council, 2025) requires high-quality recycled polypropylene (rPP). Mechanical recycling, however, is challenged by heterogeneous feedstocks and contamination (Eriksen et al., 2019). This study evaluates how object-based sorting and washing intensity affect recyclate performance and environmental impacts.
Dutch post-consumer rigid PP was sorted into white, clear, and colored fractions, subjected to cold wash, hot wash, and additional hot wash (hot wash+). Subsequently, the obtained fractions were extruded and converted into cups by injection molding (100 % rPP) or thermoforming (42 % rPP in multilayer cups). Material and product properties were characterized mechanically and chemically. A streamlined life cycle assessment (LCA) compared conventional recycling (simple-MR: cold wash only) with advanced recycling (advanced-MR: additional sorting, hot wash, hot wash+). Functional units were (i) 1 ton of pre-sorted PP bales ("waste perspective") and (ii) 1 kg of cup material ("product perspective"). Climate change (CC), cumulative energy demand (CED), and cumulative exergy demand (CExD) were assessed.

RESULTS

Sorting improved feedstock homogeneity and yielded more consistent recyclate properties. Hot wash and hot wash+ only slightly enhanced oxidation stability and ductility, but did not significantly reduce volatile organic compounds (VOCs) or overall migration levels in the produced cups. At product level, both injection-molded and thermoformed cups yielded a satisfactory top load performance compared to virgin PP reference cups. Thus,

the obtained recyclates were suitable for rigid packaging applications, though additional washing did not translate into benefits at product level.

The LCA results depicted in Fig. 1a illustrate the climate change impact for the recycling of 1 ton of PP waste ("waste perspective"). Here, advanced-MR, which involves additional sorting and hot washing, consistently showed higher emissions than simple-MR with only cold washing. The increase stems from a higher electricity demand, used washing chemicals, and material losses, which are assumed to be directed towards incineration eventually. Hot washing in particular raised impacts without delivering corresponding improvements in recyclate performance, positioning cold washing as the environmentally preferable option at this system level.

The "product perspective" displayed in Fig. 1b, which evaluates 1 kg of cup material, demonstrates the decisive influence of substitution rates. Injection-molded cups, produced entirely from recyclate, achieved the largest reductions in climate change, cumulative energy demand, and cumulative exergy demand compared to virgin polypropylene. By contrast, thermoformed cups required blending with virgin material and therefore reached only 42 % recyclate content, which limited their environmental benefits despite following the same recycling routes. The comparison of cold wash, hot wash, and hot wash+ scenarios confirms that additional washing did not increase recyclate substitution potential, while simultaneously increasing process burdens. As a result, scenarios with higher recyclate incorporation consistently outperformed those with more intensive washing.

Overall, the results demonstrate that substitution rate, rather than washing intensity, is the dominant driver of environmental performance. Maximizing recyclate use in final products enables substantial reductions in greenhouse gas emissions and energy demand, while resource-intensive washing provides only marginal benefits at higher environmental costs.

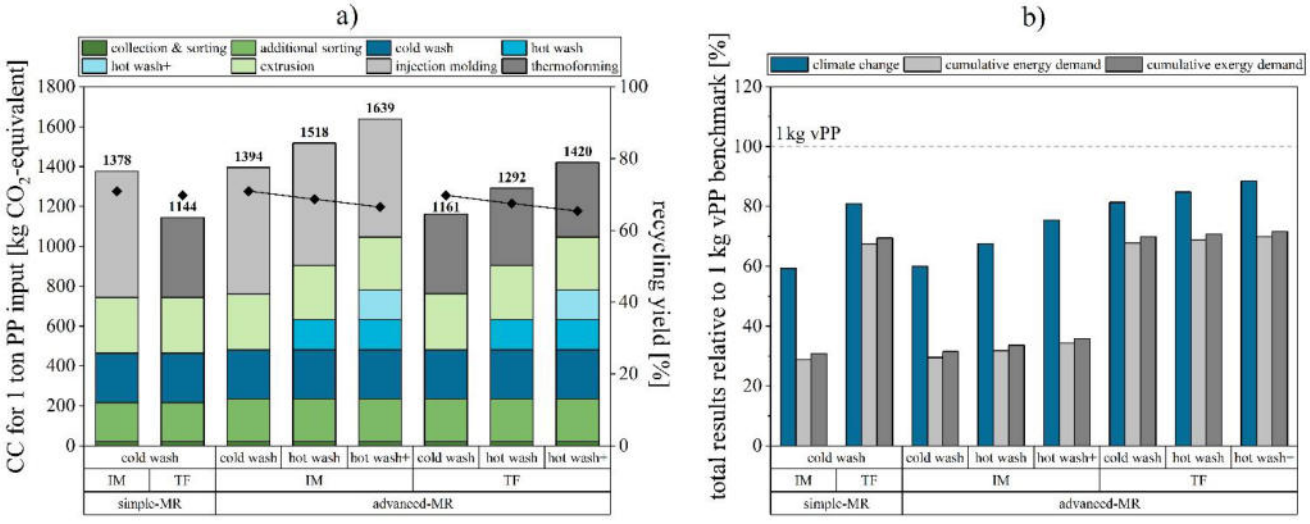


Fig. 1: a) Total impact on CC for the recycling of 1 ton of presorted PP bales using different washing procedures and b) product perspective for 1 kg of PP cups including CC and cumulative results for CED and CExD.

REFERENCES

European Parliament and the Council, (2025), Regulation (EU) 2025/40 of the European Parliament and of the Council of 19 December 2024 on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC. https://eur-lex.europa.eu/eli/reg/2025/40

Eriksen, M. K., Christiansen, J. D., Daugaard, A. E., & Astrup, T. F., (2019), Closing the loop for PET, PE and PP waste from households: Influence of material properties and product design for plastic recycling. Waste Management, 96, 75–85. https://doi.org/10.1016/j.wasman.2019.07.005

CONFERENCE TOPIC

2.04 Life Cycle Assessment
(1.03 Circular Economy Strategies for the Energy Transition)

TOPVIEW: CLOSING DATA GAPS IN URBAN ENERGY AND CLIMATE PLANNING WITH REMOTE SENSING AND AI

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SUMMARY

This paper highlights the potential of remote sensing as a catalyst for integrated spatial energy planning and climate adaptation. Building on the Austrian national project TopView, it demonstrates how automated, data-driven methods enhance existing geospatial datasets and generate new information layers for municipal and regional decision-making. By combining Very High Resolution (VHR) thermal imagery, orthophotos, Geographic Object-Based Image Analysis (GEOBIA), and artificial intelligence, the project delivers scalable workflows to address critical data gaps in urban-scale planning. Five use cases illustrate the approach: (1) automated roof form classification for solar potential analysis, (2) rooftop object detection to improve energy modelling, (3) time-series analysis of urban heat islands (UHI), (4) detection of unheated buildings to refine energy datasets, and (5) integrated rooftop performance assessment combining thermal, RGB, and vegetation data. These harmonized datasets expand the scope of spatial energy planning and strengthen evidence-based climate-resilient strategies at local and regional levels.

Keywords: Remote sensing, climate adaptation, spatial energy planning, urban heat island, thermal imagery, GEOBIA, artificial intelligence, rooftop analysis

INTRODUCTION

The *TopView* project addresses the urgent need for precise, up-to-date, and integrated data to support decision-makers in the transition towards decarbonization and climate resilience. Conventional modelling methods often fail to capture the spatial and temporal complexity of urban change and thus cannot adequately support energy policy targets or climate adaptation strategies.

Remote sensing and artificial intelligence offer a transformative alternative: they enable the systematic processing of large volumes of high-resolution imagery, extraction of relevant features with minimal human intervention, and continuous updates at a pace that reflects real-world urban dynamics.

The overarching objective of *TopView* is to enhance and extend existing spatial data foundations for energy planning and climate adaptation. By combining Geographic Object-Based Image Analysis (GEOBIA), Very High Resolution (VHR) thermal imagery, and advanced AI algorithms, the project reduces the cost and time of data acquisition while expanding the scope of measurable indicators. This results in robust, scalable workflows that

empower municipal and regional authorities to develop evidence-based strategies for sustainable and climate-resilient urban development.

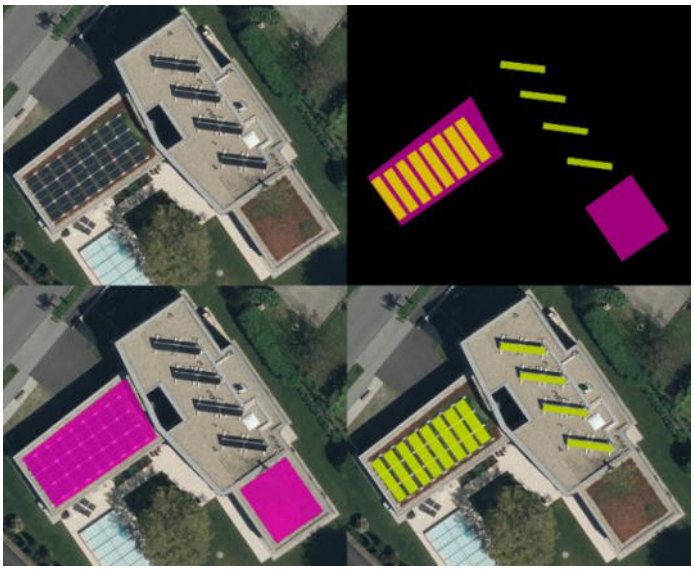
APPLICATIONS FOR REMOTE SENSING IN CLIMATE-RESILIENT ENERGY PLANNING

Municipal and regional databases often contain static or incomplete information on building characteristics, rooftop infrastructure, and urban thermal conditions. Remote sensing can address these shortcomings by providing spatially explicit, up-to-date, and comprehensive datasets that enhance the accuracy and effectiveness of spatial energy planning and climate adaptation (Manapragada, 2025).

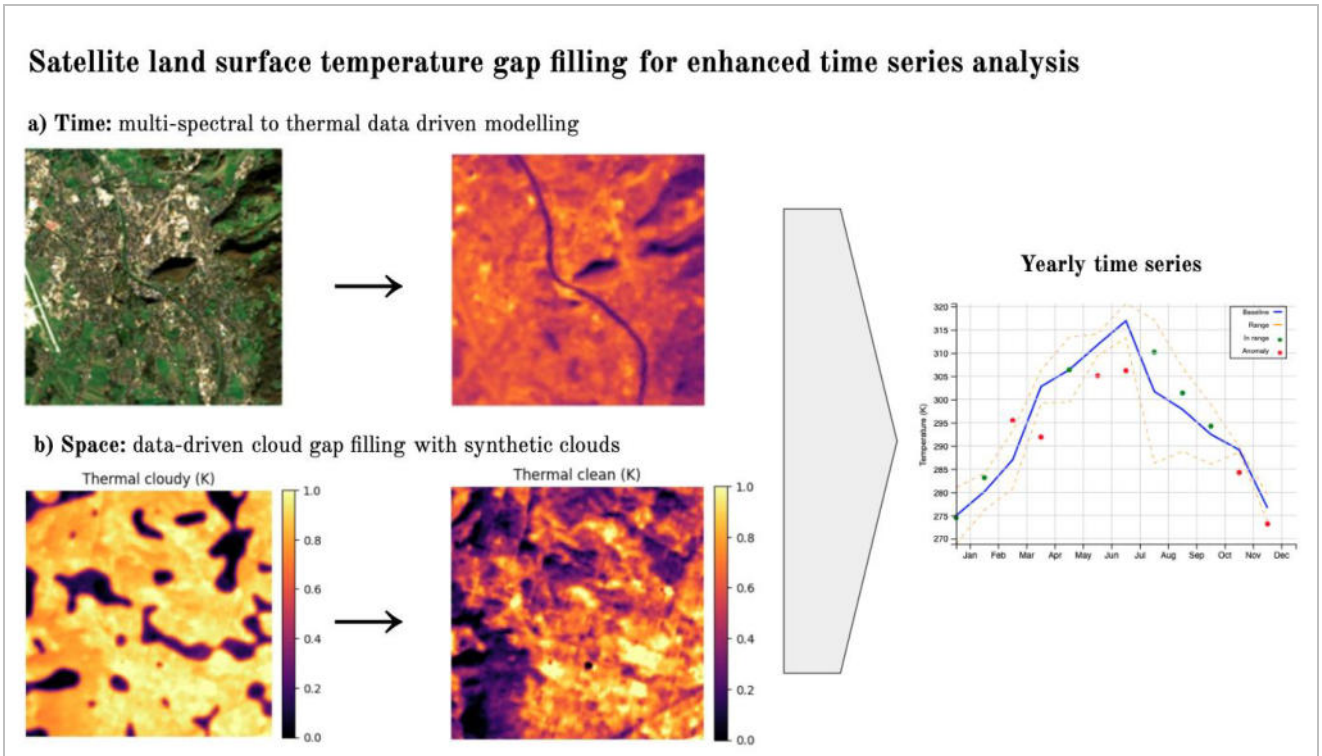
Within *TopView*, five use cases demonstrate how high-resolution imagery and automated processing create reliable, scalable data products that support planning authorities in developing evidence-based, resilient strategies. Each use case targets a specific data gap, thereby updating, refining, and extending the geospatial foundations for urban energy and climate planning.



Use Case 1: Automated Roof Form Identification for solar potential analysis (© RSA iSPACE)



Use Case 2: Automated Identification of Rooftop Objects (© N Vision)



Use Case 3: Time-series analysis of UHI for cities and regions (© Tematics)

Fig. 1: Overview over TopView use cases 1-3 (use case 4 and 5 in progress)

Use Case 1 – Automated Roof Form Identification for Solar Potential Analysis

Current methods in Salzburg and Styria struggle to distinguish roof geometries with sufficient accuracy, limiting solar energy calculations. By applying Geographic Object-Based Image Analysis (GEOBIA) to orthophotos and Digital Surface Models, *TopView* enables precise segmentation and classification of roof structures. These results improve photovoltaic (PV) potential mapping, urban energy planning, and the creation of digital building twins.

Use Case 2 – Automated Detection of Rooftop Objects

Reliable information on existing rooftop installations (e.g., PV, solar thermal, cooling units, green roofs) is often missing from urban energy datasets (Abraham Noah Wu, 2021). Using AI-based computer vision, this use case detects and classifies such rooftop objects automatically. Combined with UC1, it allows for more accurate assessments of installed PV capacity and remaining potential at building, district, and municipal level.

Use Case 3 – Time-Series Analysis of Urban Heat Islands (UHI)

Thermal datasets with adequate resolution and frequency are essential for understanding UHI dynamics but are rarely available. *TopView* applies generative AI to close cloud gaps and merge multiple thermal data sources including the Harmonized Landsat and Sentinel-2 dataset (Junchang Ju, 2025), producing continuous land surface temperature maps. When combined with climate data, these reveal persistent hot spots that inform municipal heat mitigation strategies.

Use Case 4 – Identification of Unheated or Poorly Insulated Buildings

High-resolution winter thermal imagery is used to detect unheated or insufficiently insulated buildings. This information refines existing building and energy datasets, enabling municipalities to prioritize renovation programs, district heating expansion, and targeted efficiency measures

Use Case 5 – Integrated Rooftop Performance Assessment

Green roofs and PV systems provide both energy and cooling benefits, but their combined performance is rarely measured at scale. By combining thermal, RGB, and vegetation data, this use case evaluates the temperature-

reducing effects of rooftop greening. The results support evidence-based decisions on where to invest in green infrastructure for maximum energy savings and adaptation benefits

REFERENCES

Abraham Noah Wu, F. B. (2021). Roofpedia: Automatic mapping of green and solar roofs for an open roofscape registry and evaluation of urban sustainability. *Landscape and Urban Planning*(Volume 214), 16. doi:https://doi.org/10.1016/j.landurbplan.2021.104167

Junchang Ju, Q. Z. (2025). The Harmonized Landsat and Sentinel-2 version 2.0 surface reflectance dataset. *Remote Sensing of Environment*(Volume 324), 17. doi:https://doi.org/10.1016/j.rse.2025.114723

Naga Venkata Sai Kumar Manapragada, M. M. (2025). Remote sensing for environmentally responsive urban built environment: A review of tools, methods and gaps. *Remote Sensing Applications: Society and Environment*(Volume 38), 22. doi:https://doi.org/10.1016/j.rsase.2025.101529.

ACKNOWLEDGMENT

This work is conducted within the project *"TopView – Efficient Use of Remote Sensing Data for Climate Adaptation and Energy Planning"*, funded under the Austrian TIKS program for Energy and Environmental Technologies (FFG-Project Number: FO999913467). From January 2025 to December 2026, the project develops methodologies to integrate remote sensing data into sustainable urban development and climate adaptation.

SMART CONTROL OF SMALL DISTRICT HEATING: TOWARDS AN ACTUAL IMPLEMENTATION

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SUMMARY

Small district heating networks (sDHN) will play an important role in the decarbonation of the heat delivery sector in the coming years. Smart control of the production is required to best integrate renewable and waste heat. However, deployment of smart control on an sDHN is rare and challenging, as only limited computing resources can be embedded. The present work proposes an approach to deploy smart control on an sDHN with little computing resources. A model predictive control (MPC) gives power-level instructions every 15min. An intermediate control (IC) leads the production via thermal-hydraulic commands, with respect to the MPC instructions, while ensuring state feedback in terms power for the MPC. A parametric version of the MPC was developed with machine-learning to free the approach from using mathematical solvers. Simulation tests are being conducted at the CEA-INES to evaluate the approach.

Keywords: Small district heating, Predictive control, Reduction, Storage, Controller Deployment

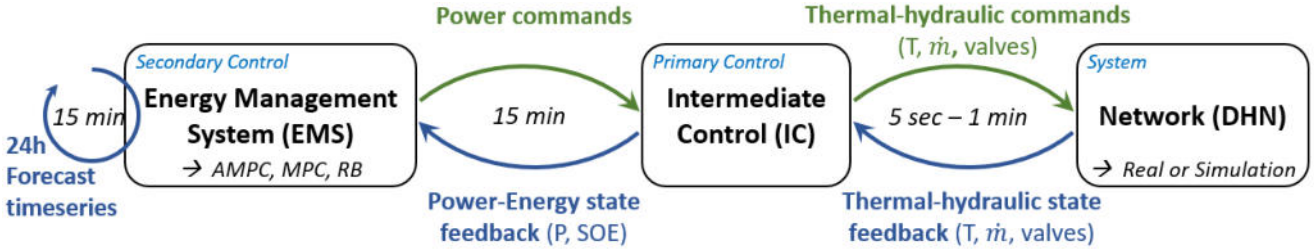
INTRODUCTION

District heating networks (DHN) are prominent tools for the decarbonation of the heat delivery sector [1]. Indeed, they can efficiently integrate renewable and waste heat [2]. Smart control of the production is required to optimize these integrations. In this context, the development of a large number of small networks (sDHN) is expected. However, the deployment of smart control schemes to sDHN faces the challenge of low computational resources, and suboptimal expert-based operation schemes are used in practice.

The present work introduces an approach tailored for the deployment of smart control onto sDHNs. First, a novel communication approach between an Energy Management System (EMS) instance and an sDHN is presented. The EMS is tailored for a power-level Model Predictive Control (MPC), but is compatible with other controls such as Rule-Based (RB). A PLC-compatible low-complexity data-driven approximation of the MPC [3] is then presented. A case study of the micro-DHN at the CEA-INES, France, assesses the feasibility of the approach.

COMMUNICATION APPROACH

Figure 42 summarizes the lightweight communication approach between the EMS and the sDHN, interfaced by an intermediate control (CI) block [4]. The EMS issues instructions and receives state updates in power levels every 15min, to limit inquiries and resource usage. The CI plays two roles. One, it translates EMS instructions



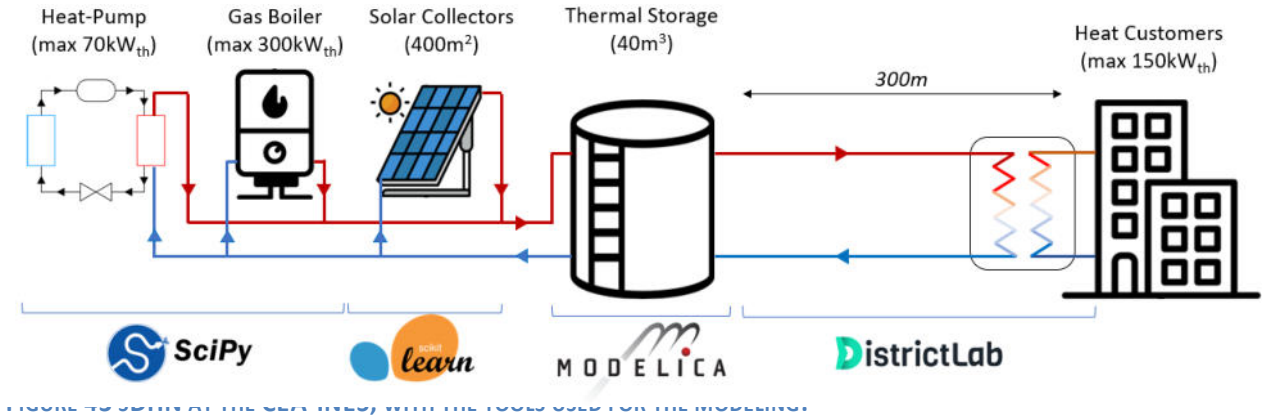
into thermal-hydraulic commands, and ensures their realization over the time step. Two, it translates the DHN state for the EMS. This includes an estimate of the State of Energy (SOE) from temperature sensors in the storage.

SMART CONTROL

Smart control of production units is ensured at the EMS. Power-level instructions allow to formulate an MPC as a light MILP problem requiring little linearization [5]. However, a mathematical solver is required, which cannot be embedded into a PLC. Consequently, a parametric version approaching the input – output relationship of the MPC (AMPC) was derived from the MILP [3]. The AMPC requires no solver, and is suitable for deployment.

CASE STUDY

The approach is demonstrated via a case study with the sDHN at the CEA-INES site in the French Alps. Figure 43 shows a schematic of the sDHN. The supply includes a solar thermal field, controllable heat-pump, boiler and thermal storage. First, models were derived from the real components, ensuring identical connectivity of the models and of the actual sDHN with the CI. Ongoing tests at the CEA-INES aim at confirming that the proposed methodology successfully controls the sDHN, and is more effective than the currently used rule-based approach. Once tests on the simulator are conclusive, they will be replicated on the actual sDHN.



REFERENCES

[1] H. Lund et al., “4th Generation District Heating (4GDH),” Energy, vol. 68, pp. 1–11, Apr. 2014, doi: 10.1016/j.energy.2014.02.089.

[2] ADEME, “Développement des filières réseaux de chaleur et de froid renouvelables en France à horizon 2050,” Nov. 2020.

[3] Z. Taïeb et al., "Mitigating Online Microgrid Controller Deployment Issues with Learning Techniques: An Approximate MPC Approach," 2024 10th International Conference on Optimization and Applications (ICOA), Almeria, Spain, 2024, pp. 1-6, doi: 10.1109/ICOA62581.2024.10754459.

[4] A. Wulveryck (2025). Model mismatch mitigation in controlling district heating networks [Master’s thesis, KTH] DiVA Portal, URN: urn:nbn:se:kth:diva-367836

[5] Runvik et al., „Production planning for distributed district heating networks with JModelica.org“, 2015, 11th International modelica conference, Versaille, France, pp.217-223, doi: 10.3384/ecp15118217.

CONFERENCE TOPIC

This abstract best refers to the two following topics: *2.07 Smart Services and System Operation* and *1.08. Future District Heating and Cooling Solutions*.

THE ROLE OF ORGANIZATIONAL LEARNING AND KNOWLEDGE MANAGEMENT FOR SUCCESSFUL BIM INTEGRATION IN LIGHTING DESIGN

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SUMMARY

Building Information Modelling (BIM) is having an increasingly significant impact on building planning and construction processes, but its implementation in lighting design remains challenging. To identify these challenges and develop solution strategies, two large-scale online surveys were conducted among stakeholders, particularly those in industry, planning, research and development. The results show that, although BIM is widely recognized as highly relevant, its integration into daily practice is hindered not only by technical limitations, such as insufficient interoperability, but also by resistance within organizational culture. This study focuses on the necessity of organizational learning to ensure long-term implementation. In addition to technological change, the implementation of BIM also requires continuous organizational learning processes to align individual skills with collective structures. The study's results particularly break down organizational workflows and how these are linked to technical requirements.

INTRODUCTION

Technological innovations and digital transformation are changing industries at an unprecedented pace. In the construction sector, Building Information Modeling (BIM) is one of the most important drivers of change, promising more efficient planning, improved collaboration, and enhanced building lifecycle management (Abanda, et al., 2025, Oraee, et al. 2019). Despite its advantages, BIM implementation still faces challenges. In lighting design in particular, the implementation process is characterized not only by technical complexity but also by organizational resistance. Traditional procurement and planning methods are deeply rooted, making the transition to digital and collaborative workflows challenging. While previous planning processes were decentralized, the BIM model functions as a central collaboration platform (Abanda, et al., 2025, Oraee, et al. 2019).

Although BIM facilitates explicit knowledge sharing through shared models, it does not automatically support implicit learning or flexible discussions. This underscores the importance of organizational learning, understood as the ability of organizations to adapt structures, processes, and knowledge bases to external and internal stimuli (Crossan et al. 1999). The transition to BIM therefore requires more than just the implementation of software; it requires a reconfiguration of roles, responsibilities, and decision-making processes. This transition requires breaking down existing patterns of thinking and replacing them with new strategies, corresponding to an accommodative learning process that requires profound changes.

METHODOLOGY

Against the backdrop of sustainable BIM integration, this study examines the current perception and implementation of BIM in lighting design, focusing in particular on organizational aspects. Two different surveys (2023 and 2024) were conducted with stakeholders from various sectors. The associated questionnaires were distributed via national and international lighting associations. In total, 195 usable responses (123 and 72) were received.

The objective of the study is to collect and secure empirical evidence on the challenges that currently exist, the perceptions of stakeholders, and the effective measures that can be taken to overcome the barriers to BIM implementation. Particular focus is placed on the interplay between individual and organizational learning processes, since BIM implementation is a continuous transformation cycle, not a one-time project. By combining empirical results from questionnaires with a conceptual perspective on organizational learning, the study will contribute to our understanding of how the construction industry can develop adaptability and meet the demands of greater digitalization.

FINDINGS

The questionnaire results reveal a discrepancy between perceived importance and practical implementation. In the first survey, approximately half of the participants rated BIM as relevant. However, more than 70% described the available information as unclear, and almost 60% found working with BIM rather difficult. At the individual level, organizational members must have the necessary knowledge and willingness to learn new workflows. Investments in user-friendly software solutions, training, and targeted employee development significantly accelerate the establishment of digital structures. The speed of organizational learning processes is thus closely linked to an organization's financial capabilities. Small businesses, in particular, reported financial strains in this context.

The knowledge gained is disseminated through internal communication structures, informal learning, and organizational meetings. Through this dialogue, assumptions are reviewed, adjusted, and solidified within the organization. The commitment of organizational members is crucial in establishing learning as a permanent task and thus making the potential of BIM accessible within the company. The first step here is to create acceptance for the topic. Furthermore, it is clear that organizational learning is not a linear but a dynamic process in which disruptions and discrepancies can also provide positive impetus for further development. Without embedding BIM in organizational processes, its long-term establishment remains uncertain.

REFERENCES

Abanda, F. H.; Akintola, A.; Tuhaise, V. V.; Tah, J. H. M. (2025) BIM ontology for information management (BIM-OIM), Journal of Building Engineering 107, 112762.
Oraee, M.; et al. (2019) Collaboration barriers in BIM-based construction networks: A conceptual model, International Journal of Project Management 37, 839–854.
Crossan, M.; Lane, H. W.; White, R. E. (1999) An organizational learning framework: From intuition to intuition, Academic management review 24, 522-537.

CONFERENCE TOPIC

IT Solutions and Artificial Intelligence; Smart Services and System Operation;

IDENTIFICATION AND UTILIZATION OF PHOTOVOLTAIC RESOURCES: A FOCUS ON URBAN HIGH-DENSITY AREA DISTRIBUTION LAWS

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SUMMARY

This study focuses on exploring the distribution law of photovoltaic (PV) samples in urban high-density areas to support scientific planning and efficient utilization of urban PV resources. It adopts a high-precision machine learning semantic segmentation method optimized based on multi-spectral images—this method leverages the fine spectral information of multi-spectral images to more accurately identify targets like PV panels, enhancing statistical accuracy and detail. Typical high-density cities (e.g., Beijing, Shanghai, Guangzhou) are selected as research objects for their diverse characteristics in population, economy, geography, and urbanization. The study analyzes PV from horizontal (global distribution, cross-regional method adaptability, factor correlations) and vertical (temporal dynamic changes, urbanization interaction) dimensions, and uses GIS to identify building outlines/types, coupling with energy demand analysis to excavate high-PV-potential buildings. Ultimately, it aims to summarize PV distribution laws and provide references for policymakers to promote sustainable urban PV development.

Keywords: PV distribution, urban high-density areas, multi-spectral images, Geographic Information System (GIS), PV planning

ABSTRACT

This study is dedicated to an in-depth exploration of the distribution law of photovoltaic (PV) samples in urban high-density areas, so as to facilitate the scientific planning and efficient utilization of urban PV resources. A high-precision statistical method for the distribution of existing PV facilities optimized based on multi-spectral images is adopted in this research. This method can more accurately identify targets such as PV panels through the fine spectral information of multi-spectral images, thereby improving the accuracy and detail of statistics.

Firstly, a number of typical high-density cities across the country are carefully selected as research objects, including Beijing, Shanghai, Guangzhou, Shenzhen, Chengdu, Xiamen, etc. More cities that meet the conditions can be included according to research needs in the future. These cities have their own characteristics in terms of population density, economic development level, geographical and climatic conditions, and urbanization process, providing rich and representative samples for a comprehensive analysis of the PV distribution law.

Then, a comprehensive analysis of PV-related situations is carried out from both horizontal and vertical dimensions. In terms of the horizontal analysis of PV distribution, the focus is on the global PV distribution situation. On the one hand, the cross-regional adaptability of existing PV identification and statistical methods is studied, aiming to clarify the applicable scope and limitations of existing methods in different geographical environments (such as different climate zones and topographical areas), so as to provide a basis for the optimization and cross-regional application of the methods. On the other hand, the correlation between PV distribution and various factors such as population, economy, geography, and climate is deeply explored. These

factors cover multiple dimensions such as physics (such as terrain and lighting conditions), geography (such as regional location and land use type), and society (such as population size and structure, and economic development level). By analyzing their interaction with PV distribution, the internal driving mechanism of PV deployment in different regions is revealed.

For the vertical analysis of the PV development trajectory, the focus is on the dynamic change of PV distribution over time, sorting out the development context and spatial expansion characteristics of PV in cities in different periods. At the same time, the relationship between PV development and the urbanization process is analyzed, exploring how the urban performance, such as population agglomeration, land development, and infrastructure construction, affects the development of PV, and how PV development reacts to the optimization of urban energy structure and sustainable development, so as to clarify the interaction law between the two.

In addition, the excavation of potential high-PV-potential areas is actively carried out. With the help of the Geographic Information System (GIS), the building outlines and building types in cities are accurately identified. On this basis, through coupling with building energy demand analysis, the buildings without PV installation are systematically evaluated, and high-value buildings for PV development are selected. Such buildings usually have good PV installation conditions, such as having a suitable roof area and orientation, and relatively strong energy demand. After installing PV, they can generate significant energy benefits and economic value.

By integrating the analysis results of the above multiple dimensions, this study expects to summarize the distribution law of PV in urban high-density areas and provide valuable reference for policymakers, urban planners, and practitioners in the energy field. These insights help relevant personnel make wiser decisions in the process of planning, construction, and management of urban PV systems, thereby promoting the urban PV systems to develop in a more sustainable direction and facilitating the realization of urban energy transformation and low-carbon goals.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
1.12. Next-Generation Technologies for Renewable Energy and Resource Efficiency

OPTIMIZING ENERGY IN SINGLE-FAMILY HOMES: FROM BIOMASS BOILERS TO HEAT PUMPS

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SUMMARY

Many different components for heat or electricity generation have been implemented in single-family homes in recent years. The efficient use of the controllable components while harvesting the volatile renewable sources and satisfying the energy consumption has become increasingly difficult. For this, we developed a modular, predictive, optimization-based control framework now deployed in more than 200 single-family homes. While initially the biomass boiler has been controlled, the focus has been extended to heat pumps. However, this shift is not straightforward, since heat pumps are typically paired with smaller buffer sizes, limiting flexibility. At the same time, heat pumps also allow for other optimization potential, e.g. time-varying electricity prices and coefficient of performance. In our contribution, we present results from real-world implementations and discuss the potential and the challenges arising with this shift from biomass boilers to heat pumps.
Keywords: Energy Management System, Model Predictive Control, Sector Coupling, Flexibility

INTRODUCTION

In recent years, the components used to supply energy to single-family homes have undergone a significant transformation. Traditionally, the focus was on boilers for heat generation, with a gradual shift from oil and gas systems to biomass boilers. Biomass boilers are typically paired with large thermal buffers, as their relatively slow response times contrast with end users' expectations for immediate heat delivery.

More recently, compression heat pumps have become increasingly popular as the primary heat source for single-family homes. Compared to biomass boilers, heat pumps can deliver heat more quickly and on demand. This allows for much smaller thermal buffer storage volumes. Smaller buffers are attractive because they have lower investment costs, require less space, and reduce thermal losses when stored heat goes unused. However, larger buffers offer better operational flexibility—for example, enabling the heat pump to run during periods where surplus electrical power from photovoltaics is available, where electricity prices are lower, or where a higher coefficient of performance can be achieved. Such flexibility can be used to significantly reduce operating costs, which remains a major concern for private households.

Many single-family homes now operate as multi-energy systems, integrating several energy sources, where some may be volatile. These can be optimized through supervisory control systems designed to use heat and electricity as efficiently as possible within the household. If the control systems are predictive, they can also effectively employ the flexibility provided by the energy storage. Looking ahead, this flexibility will also be critical for developments such as demand-side management, where a higher-level supervisory control of an energy supplier can help shifting household energy demand to flatten peak loads.

OPTIMIZATION-BASED CONTROL FRAMEWORK

An optimization-based control framework has been developed that can consider the a) energy production of various components of a multi-energy system, including biomass boilers, photovoltaic systems, solar thermal plants, power-to-heat devices (e.g., heat pumps and heating rods), b) energy storage in thermal buffer storages, and c) consumption such as domestic hot water, space heating and electrical power consumption. The framework's modular design enables the optimization problem to be tailored to the given system configuration, making it particularly suitable for residential applications.
To exploit system flexibility, forecasts of the weather, the volatile energy generation and the heat and electricity consumption are required. Using these forecasts, a mixed-integer linear programming (MILP) optimization problem is solved, and the resulting schedules for the heat-producing components are transmitted to the controllable devices.

REAL-WORLD IMPLEMENTATION AND CHALLENGES

The optimization-based control framework as first presented in (Moser, et al., 2020) is currently implemented in more than 200 single-family homes. While most installations still use biomass boilers, first results with heat pumps have been obtained under varying hydraulic configurations—both with and without thermal buffers, and with different buffer sizes, revealing specific differences in their operational characteristics. In our contribution, we present the results from real-world implementations and discuss the differences when using the heat pump instead of the biomass boiler:
First, the transition from biomass boiler to a heat pump as the primary heat source at first seems to be relatively straightforward: the optimization ensures that the thermal buffer contains sufficient energy to meet the predicted consumption until the heat source can be operated in an efficient way. Since a biomass boiler is slow, a larger thermal buffer is required, while heat pumps are often installed with much smaller thermal buffers (e.g., around 200 litres). However, heat pumps should operate at lower feed temperatures, since the coefficient of performance of the heat pump depends on it: although the thermal buffer might be able to store more energy, the coefficient of performance of the heat pump would decrease, resulting in less thermal energy for the same electrical energy used and thus in higher costs.
Second, heat pumps can be operated without a thermal buffer storage. In a first approach, a simple low-level solution has been implemented, while the second approach involves the building mass as thermal storage, which is currently investigated.
Third, the heat pump in the multi-energy system allows to consider other potential for optimization, e.g., time-varying electricity prices or to use the surplus power from photovoltaics.
Fourth, a heat pump can be operated with smaller minimum up- or downtimes, resulting in a different evaluation of a reasonable operation and in a different operating strategy. Thus, in our contribution, we will present the results from real-world implementations and discuss the challenges when shifting focus of control from biomass boiler to heat pumps while keeping in mind the flexibility of the overall system.

REFERENCES

Moser, A., Muschick, D., Gölles, M., Nageler, P., Schranzhofer, H., Mach, T., . . . Hofer, A. (2020). A MILP-based modular energy management system for urban multi-energy systems: Performance and sensitivity analysis. *Applied Energy*.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
Digitalization for Smart, Resilient Energy Systems, Coupling of Energy Sectors

PRODUCTION OF H2 FROM AL-WATER REACTIONS, EVALUATION OF PARAMETERS FOR AN AL-TO-ENERGY PROTOTYPE OPERATION

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SUMMARY:

Seasonal energy storage is essential to address renewable energy fluctuations. Renewable Metal Energy Carriers (ReMEC), particularly aluminium (Al), offer high potential due to abundance, low cost, and high energy density. In the Power-to-Al process, renewable electricity reduces Al_2O_3 into elemental Al, while in the Al-to-Energy process, Al reacts with water to produce hydrogen, heat, and $Al(OH)_3$. $Al(OH)_3$ can then be converted to Al_2O_3 to close the material cycle. This study investigated the Al-water reaction in alkaline solutions (<100 °C) and supports the design of a 4 kW Al-to-Energy prototype by investigating suitable temperature, alkalinity, aluminate concentration and Al feed properties for fast energy release. $Al(OH)_3$ recovery by precipitation was also studied to define boundary conditions to balance hydrogen production and $Al(OH)_3$ recovery for efficient prototype operation.

Keywords: ReMEC, MeCRE, Aluminium, seasonal energy storage, Al-water reaction, power-to-X

INTRODUCTION:

Seasonal energy storage represents a key solution to the fluctuation of renewable energy throughout the year. Renewable Metal Energy Carriers (ReMEC) are highly suitable materials for large-scale seasonal energy storage. Among them, aluminium (Al) is particularly promising due to its high abundance, low cost, and high volumetric energy density. In places or at times of high abundance of renewable electricity, this electricity is used to convert aluminium oxide into elementary Al by a carbon free inert anode smelter process (Power-to-Al). When the energy demand is high and renewables are short in winter season, Al is oxidized by water in an exothermic reaction that produces hydrogen and heat; the hydrogen may subsequently be used to produce electricity in a fuel cell (Al-to-Energy) or to produce heat in a hydrogen burner.

This study focuses on the Al-water reaction in alkaline solutions (<100ºC), which, besides heat and H_2, leads to the formation of aluminium hydroxide ($Al(OH)_3$). Different reaction parameters were tested with the aim of assisting the design of a 4 kW Al-to-Energy prototype. Thus, laboratory experiments were performed using commercial Al 6060 alloy granules - obtained by cutting of extruded wires - to evaluate effect of: 1) temperature and alkalinity of solution, 2) presence of aluminate ions, and 3) morphology of Al granules.

As expected, the results showed an exponential response of the reaction rate with the temperature and alkalinity. Importantly, the study allowed to propose temperatures and NaOH molarities up to 70 ºC and 3 M as suitable conditions for the prototype because no significant rate acceleration was observed at harsher conditions. The presence of aluminates decreased significantly the Al discharge rate, especially with aluminate concentrations above the solubility limit (C_e). The critical concentration (C_{cr}) for spontaneous precipitation was determined at conditions relevant for the operation of the Al-to-H_2 prototype (i.e. 65ºC, 2M NaOH and stirring).

The experimental results for different Al 6060 granule shapes (cylindrical vs rounded) and sizes (0-6-1.2 mm) showed strong dependence between granule morphology and reaction rates. A combination from reactor testing, microscopy analysis and data fitting to relevant mathematical models indicate that Al6060 granules obtained by extrusion develop porous structure during reaction. This pore formation accelerates reaction kinetics, making such granules particularly suitable for ReMEC applications.

For a continuous operation, the Al-to-Energy prototype requires to recover the $Al(OH)_3$ formed during reaction by precipitation. Therefore, efforts were devoted to understand the precipitation process under the conditions relevant to prototype operation (i.e. 30-80 ºC, 2 M NaOH). The parameters evaluated comprise: 1) temperature, 2) the use of seeds and 2) degree of aluminate supersaturation. Titration, X-ray diffraction, dynamic light scattering, and microscopy studies of the $Al(OH)_3$ recovered evidenced a strong dependence between experimental conditions, reaction kinetics and the obtained polymorph and particle size under such conditions.

To conclude, the authors will discuss how the various parameters studied can be tuned to find a compromise between H_2 production and $Al(OH)_3$ recovery in a 4 kW Al-to-Power prototype. The boundary conditions and operational limitation will be assessed while prototype design strategies will be compared.

FIGURES

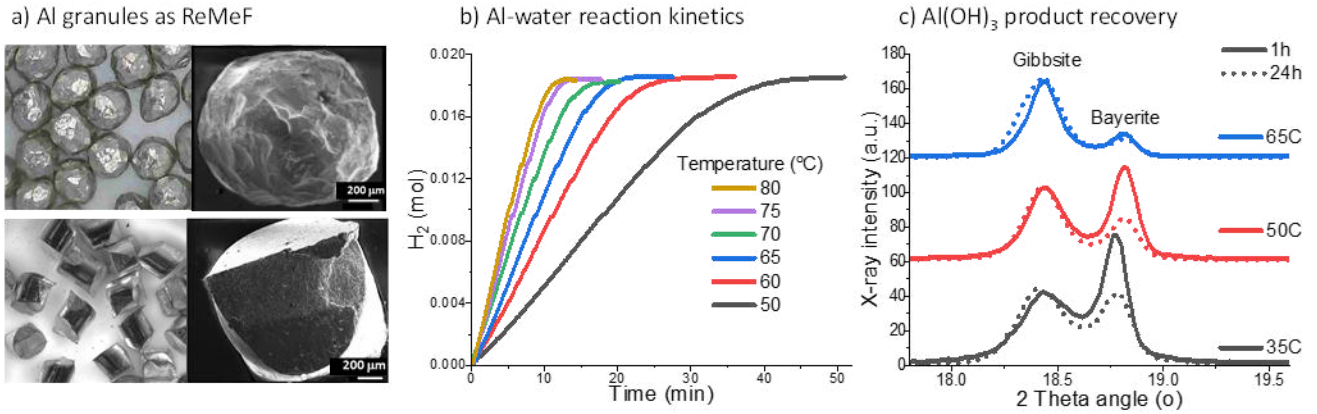


Fig. 1: The work evaluates the use of Al6060 granules as the ReMEC and studies suitable parameters for performing Al-water reaction in alkaline solution as well as the recovery of $Al(OH)_3$ in an Al-to-Energy prototype. A) microscopy images of different Al6060 granule morphologies studied, b) Al-water kinetics tested at different temperatures, and c) X-ray diffraction patterns of $Al(OH)_3$ recovered during precipitation at different times and temperatures.

REFERENCES

[1] M. Agote-Arán, B. Welte, R. Freeman, N. Mutti, M. Haller, A. Heel, Al6060 cut wire granules for Al-water reaction: Evaluation of reaction conditions and granule treatments, International Journal of Hydrogen Energy, 117, (2025) 430-441. [2] M. Teichert, M. Haller, F. Sick, Aluminium redox cycle in comparison to pressurized hydrogen for the energy supply of multi-family houses, Applications in Energy and Combustion Science, 12, (2023). [3] M. Haller, D. Amstad, M. Dudita, A. Englert, A. Häberle, Combined heat and power production based on renewable aluminium-water reaction, Renew. Energy 174 (2021) 879-893.

CONFERENCE TOPIC

Next-Generation Technologies for Renewable Energy and Resource Efficiency

COMMUNITY OWNED VIRTUAL POWERPLANTS: SUPPORTING OUR MODERN ELECTRICITY GRIDS

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SUMMARY

Virtual Powerplants (VPPs) are smart systems that combine renewable energy sources and battery storage to stabilize the grid and optimize energy use. They rely on dynamic electricity pricing, smart meters, and market access through aggregators. Energy communities can benefit from VPPs by increasing revenue and improving self-consumption, though implementation is complex and still in pilot stages.

Keywords:
- Energy transition
- Smart grids
- Virtual Powerplants
- Battery Energy Storage Systems
- Energy Communities

INTRODUCTION

The transition of our electricity production away from fossil-based sources to renewable sources bring some challenges with it. While the costs of renewable energy production is cheaper than fossil based, the required modifications of our electricity grids are often underestimated. In order to incorporate wind power, PV solar systems, EV charging, heatpumps and other “new” technologies, our electric grids need to be modernized and expanded. This role is given to the local grid operators (distribution system operator - DSO), as well as on a high level the transmission system operators – TSO’s. The implementation is mostly technical hardware, such as upgrading transformer stations, building new cables, adding battery energy storage systems. This poses severe challenges, because the upgrading of the grid is a slow process that requires high investment costs.
Another problem are the high price fluctuations in the exchange market for electricity, for example for the day-ahead prices. In markets with a high share of renewable energy production, the price differences between night and day, or sunny vs. cloudy days can vary significantly. Even negative prices are getting more common, when supply exceeds demand.

A potential solution lies in expansion of energy storage, but also in software. When energy storage technologies are combined with smart software systems, the benefits to our electrical grids can be huge. One of these solutions that is already now implemented by power companies is a virtual powerplant (VPP) system. This VPP combines distributed energy resources (DER) such as PV solar, wind turbines, biogas plants with electrical energy storage technologies such as battery energy storage systems (BESS), pumped hydro storage or compressed air storage. The key part is a software that can charge and discharge the energy storage when required. This feature allows a much higher grid supporting feature, and also enables a more profitable business, compared to a system that does not have a VPP in place.

An important feature of the VPP software is the prediction of power production and power consumption in the near future, e.g. for the next 24h . With this feature, a decision can be made whether the energy produced is stored in the energy storage system, or whether the energy should be used for own consumption on-site, or whether the energy should be sold to the grid.

ELEMENTS OF A VIRTUAL POWERPLANT

A VPP requires certain factors in order to work. These are the following:

- Exchange traded electricity with dynamic prices

  The dynamic prices of electricity on the spot market are required. When dynamic prices are in use, the price difference between the cheapest 15 minute, or 1h interval of the day, compared to the most expensive time of the day will significantly influence the business case profitability. The higher the price difference in the spot price of electricity, the more profitable business a VPP can create.
- Open free market that is not regulated by a single monopoly.

  A free market that allows competition is required. In markets that only have one single supplier to electricity, a VPP system is unable to be implemented.
- Smart electricity meters

  A key feature is the use of smart meters. In markets that do not use smart meters, a VPP will not be able to operate.
- An aggregator that is trading the electricity on the wholesale market.

  The trading of electricity on the wholesale market requires a trading license. Aggregators that communicate with end customers DER resources and energy storages can fulfil this role. Such aggregator can be the electricity supplier, or an own separate company that only specializes on this business.

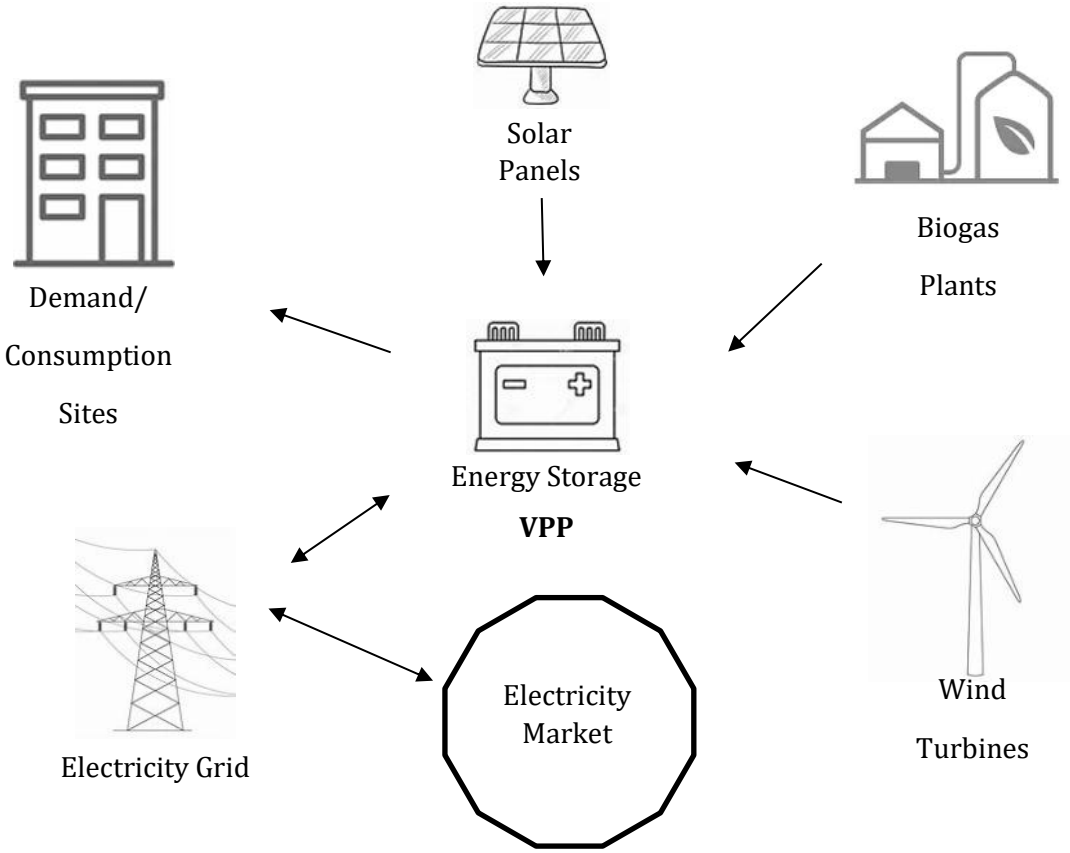


FIGURE 44: OVERVIEW OF A VIRTUAL POWERPLANT SYSTEM.

(OWN ILLUSTRATION FROM COPOWER PROJECT AND INPUT FROM (ANNE MARIE MCLAUGHLIN, 2022))

ENERGY COMMUNITIES ROLE IN VIRTUAL POWERPLANTS

Energy communities play an important role in the energy transition. The local decentralized approach of energy communities is beneficial for a socially accepted change away from fossil-based energy sources to renewable. When combining the role of VPP's with energy communities, the benefits of DER resources, such a PV solar panels or wind turbines, can generate a higher revenue, compared to a situation without VPP's. This is because of the smart software that is able to generate higher income from selling energy to the public grid when prices are high, and also because the self-consumption of electricity is optimized.

VPP's, however, require a complex software system that communicates between the DER resources, energy storage, consumption side and the electricity market. Due to that fact, VPP's have so far not been implemented in energy communities. Some pilot projects, such as the CoPower project where the author is working in, are trying to pilot new solutions. The results of these pilot demonstration case will be finalized during this winter 2025.

CONCLUSION

VPP's play an increasingly important role in our electricity system. The benefits of smart energy solutions, such as VPP's combined with BESS, yield to commercially successful implementations. On a local, de-centralized level, the implementation is slower, due to the small scale, and the local requirements that differ in each case. New pilot demonstrations have tackled that issue, and the results will be presented in this publication.

REFERENCES

Anne Marie McLaughlin, 2022

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

- **Digitalization for Smart, Resilient Energy Systems**

THE ROLE OF ICTP IN ENERGY-EFFICIENT APPLIANCE MANUFACTURING AND VALUE CHAINS FOR AFRICA'S JUST ENERGY TRANSITION

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SUMMARY

Local manufacturing of cleantech, on- and off-grid appliances is a critical pillar for Africa's industrial and energy transition. Within the **Energy Efficiency for Sustainable Livelihoods in Africa (EELA) programme**, focus areas include productive-use appliances such as solar water heaters and pumps, cooling appliances and industry clean-tech equipment. Building regional value chains for these appliances reduces reliance on imports, improves affordability, and creates local jobs.

At the same time, the introduced **Industry Clean-Tech Platform (ICTP)** provides a complementary mechanism that connects manufacturers with finance, technology providers, and industrial demand, ensuring that efficiency gains reach both households and industries. By acting as a **catalyst for industrial innovation and investment**, ICTP transforms isolated appliance interventions into **systemic industrial change**. Together, EELA and ICTP strengthen Africa's energy efficiency by accelerating sustainable energy innovation, enabling industrial decarbonization, and fostering global partnerships for a just energy transition.

Keywords: Africa, EELA, ICTP, local manufacturing, cleantech, value chains, industrial decarbonization

INTRODUCTION

Appliances are the "last mile" of **energy access**. In **Africa**, **refrigerators**, **lighting devices**, and **productive-use appliances** account for a large share of **household** and **SME electricity demand** (IEA, 2022). However, most are **imported** and often **unsuited for local conditions**. This mismatch limits the potential of appliances to drive **productive uses of energy**, hampers **local value creation**, and increases dependence on external supply chains. Strengthening **domestic manufacturing** and integrating **energy-efficient solutions** into **industrial processes** are therefore essential steps to align energy access with **sustainable industrialisation**.

For this reason, the **EELA programme** aims to:

- **Increase the uptake of EE Appliances** through national policy and capacity building interventions as well as private sector development, linked to the regional EELA Project.
- **Set up a Private Sector Industry Clean Tech Platform (ICTP)** to accelerate investments in the low-carbon transformation of the industrial sector.
- **Promote effective e-waste management and enhance institutional capacity** to manage and regulate e-waste.

The **ICTP framework**, managed by UNIDO, complements EELA by **creating demand for low-carbon technologies in industrial spaces, facilitating access to finance, and connecting solution providers to local manufacturers**. This dual approach ensures that efficient appliances are not only produced locally, but also widely adopted by households and industries, embedding them into Africa's industrialisation and climate strategies.

VALUE CHAIN PERSPECTIVES AND THE ROLE OF ICTP

The **EELA programme** recognizes that the **transformation** of African **industries** towards **energy efficiency** and **low-carbon pathways** requires **systemic approaches** that go beyond single interventions. **Value chains** in **agro-industry**, **mining**, **manufacturing**, **energy** and **water** face persistent **barriers** such as **outdated technologies**, **high production costs**, **limited access to finance** and **insufficient technical know-how**. The **Industry Clean-Tech Platform (ICTP)** addresses these barriers by acting as a **one-stop hub** where industries can access **sectoral information**, **technology providers**, **financing opportunities** and tailored **support services**, including **training** and **energy management systems**. By integrating **clean technologies** into **industrial value chains**, the **ICTP** stimulates **competitiveness**, **job creation** and **environmental sustainability**, while ensuring that **energy efficiency measures** become embedded in broader **industrial development processes**.

The **Industry Clean-Tech Platform (ICTP)** strengthens all three stages by:

- Facilitating partnerships between **solution providers and local manufacturers**, offering preferential terms for components and technology transfer.
- Linking manufacturers and SMEs to **financial products** and catalytic grants that de-risk investments in new production lines.
- Creating **industrial demand** through audits, training, and energy management systems, which stimulate adoption of efficient appliances in industrial zones.

This integration ensures that appliance manufacturing is not an isolated intervention, but part of a **systemic transformation of African value chains**. **Figure 1** illustrates the ICTP governance and operational model, showing how funding partners, UNIDO, advisory agents, financial products, and solution providers are connected to industries and industrial spaces. In the EELA context, these linkages ensure that **locally manufactured lighting, refrigeration, and productive-use appliances** can move seamlessly from design and assembly into **industrial adoption and large-scale deployment**.

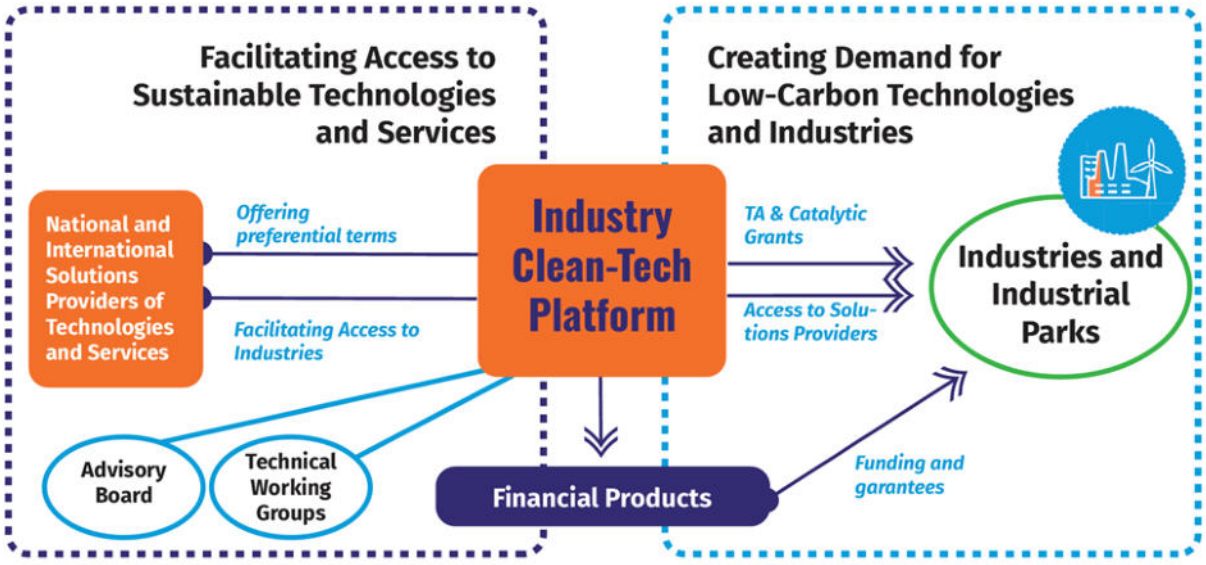


Fig. 1: Industry Clean-Tech Platform (ICTP) enabling appliances value chains

TENTATIVE PROPOSED FORMAT & AGENDA (90 MINUTES)

Opening (15 min):

- Welcome remarks by UNIDO leadership and Sida.
- High-level keynote (African government representative).

Session – Mobilising Finance & Scaling ICTP (35 min):

- ICTP as a platform for linking manufacturers, SMEs, and financiers.
- Insights from AfDB, EU, and private sector partners.

Interactive Panel & Q&A (30 min):

- Perspectives from policymakers, manufacturers, SMEs, and donors.

Closing & Next Steps (10 min):

- Summary of outcomes, invitation to join ICTP partnerships.

PARTNERS AND SPEAKERS

- **UNIDO:** Programme lead
- **Sida:** Donor representative
- **Regional Partners:** AFREC, AUDA-NEPAD, EACREEE, ECREEE, SACREEE
- **National Partners and private sector associations:** KAM (Kenya), ZAM (Zambia), CZI (Zimbabwe)
- **Finance Partners:** AfDB, EBRD, EU

REFERENCES

IRENA (2024), *IRENA Innovation Week: Renewable solutions to decarbonise end-use sectors,* International Renewable Energy Agency. Abu Dhabi.

CONFERENCE TOPIC

1.03, 1.10, 1.12, 2.01 (with a focus on Africa)

BUILDING ENERGY EFFICIENCY: HOW DOES IT INTERACT WITH THE ENERGY SYSTEM AND WHICH LEVEL IS COST-OPTIMAL?

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SUMMARY

What role does building energy efficiency play in a renewable energy system? Our contribution addresses this question in two ways: First, we examine the connections between building energy efficiency and sector coupling, highlighting the advantages for both the electricity system and district heating. Put simply, lower efficiency in buildings (i.e. poorer insulation) shifts costs away from the building sector and onto the energy sector. Second, we present a meta-analysis of modelling studies that investigate how building efficiency affects the overall energy system. With respect to the cost-optimal efficiency level, we find that an electrified building stock requires at least a minimum degree of efficiency. At the same time, with an annual renovation rate of around 1-2%, total system costs are expected to remain roughly stable – they are only redistributed between the building and energy sectors. This creates room for flexibility in policymaking.

HOW DOES BUILDING EFFICIENCY INTERACT WITH THE ENERGY SYSTEM?

The effects of more efficiency in buildings on the energy system are shown in figure 1.

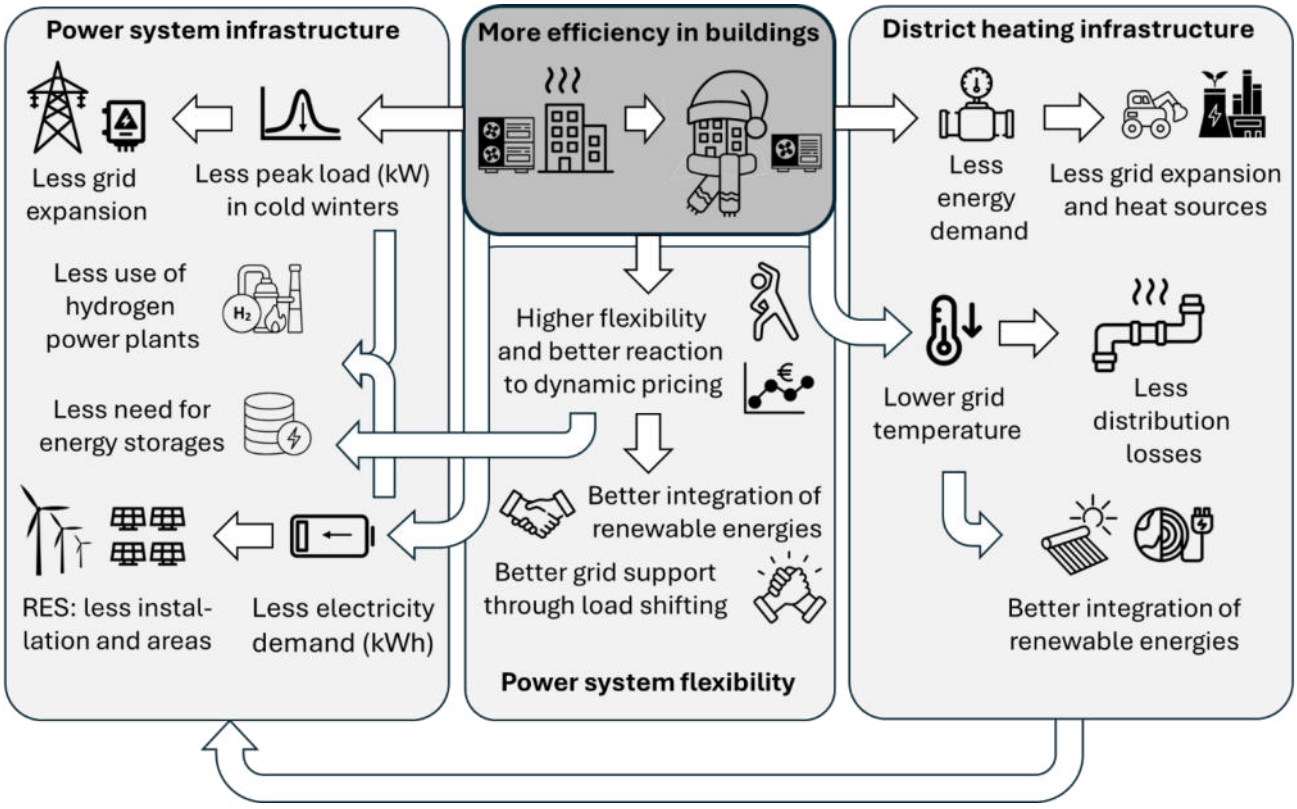


FIGURE 45: HOW HIGHER BUILDING EFFICIENCY AFFECTS THE ENERGY SYSTEM

WHAT IS THE COST-OPTIMAL BALANCE BETWEEN BUILDING EFFICIENCY AND OTHER ENERGY SYSTEM COMPONENTS?

In a meta-analysis, we compare studies that model both a low-efficiency and a high-efficiency building scenario, including projected transformation costs. By examining the differences between these scenarios within each study – and across the studies – we want to increase the understanding of the cost-optimal level of building efficiency. Based on Agora Energiewende (2018), Althoff and Wünsch (2025), Luderer et al. (2025), Mandel et al. (2023) and Zeyen et al. (2021) we come to the following findings:

1. A Minimum Level of Building Efficiency Is Essential

A stop of retrofitting activities is no option. An annual retrofit rate of 1% is at least necessary. Worst-case scenarios for the grid with peak loads must be avoided. At building level, a minimum efficiency is key for reducing flow temperatures (e.g. 55°C) and operating heat pumps cost effectively.

2. Costs are Only Shifted Between Building and Energy Sector

A higher retrofit rate than 1% supports the transition of the energy system. But between 1% and 2% per year overall system costs seem to remain constant, and it only occurs a cost shift between building and energy sector. After a basic efficiency threshold, total system costs remain nearly constant.

3. Flexibility in the Transformation Path

The cost-effective corridor likely lies between annual retrofit rates of 1-2% per year. This provides flexibility for policy makers.

Yet, securing a minimum level of efficiency in every building remains a considerable challenge. For this reason, we emphasize the importance of maintaining efficiency policies that enforce minimum standards across the entire building stock. Combined with the qualitive analysis of benefits of building efficiency for sector coupling we come the conclusion: “efficiency first but remain pragmatic – and hopeful.”

REFERENCES

Agora Energiewende (ed.) (2018): Wert der Effizienz im Gebäudesektor in Zeiten der Sektorenkopplung. Institut für Energie- und Umweltforschung Heidelberg; Fraunhofer-Institut für Energiewirtschaft und Energiesystemtechik; Consentec. Berlin.

Althoff, E. and Wünsch, M. (2025): Auswirkungen verringerter Gebäudesanierungsraten auf den Stromsektor. Eine Sensitivität des KND-Szenarios (Unpublished investigation).

Luderer, G.; Bartels, F.; Brown, T.; Aulich, C.; Benke, F.; Fleiter, T.; Frank, F.; Ganal, H.; Geis, J.; Gerhardt, N.; Gnann, T.; Gunnemann, A.; Hasse, R. et al. (2025): Die Energiewende kosteneffizient gestalten: Szenarien zur Klimaneutralität 2045.

Mandel, T.; Kranzl, L.; Popovski, E.; Sensfuß, F.; Müller, A.; Eichhammer, W. (2023): Investigating pathways to a net-zero emissions building sector in the European Union: what role for the energy efficiency first principle? In: Energy Efficiency 16 (4), pp. 1–29. DOI: 10.1007/s12053-023-10100-0.

Zeyen, E.; Hagenmeyer, V.; Brown, T. (2021): Mitigating heat demand peaks in buildings in a highly renewable European energy system. In: Energy 231, p. 120784. DOI: 10.1016/j.energy.2021.120784:

CONFERENCE TOPIC

1.04. Coupling of Energy Sectors, 1.07. Flexibility and Stability in Thermal and Electric Grids, 1.15. Sustainable Renovation and Energy Retrofits

SURPLUS ENERGY AVAILABLE AROUND EU AS AN OPTION FOR AL RECYCLING

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SUMMARY

The global energy transition requires the replacement of fossil fuels with renewables such as wind and solar energy, but their intermittent nature poses a challenge to grid stability. The REVEAL project (REVolutionary Energy storage cycle with carbon free ALuminium), introduces aluminum as a vector for making renewable energy transportable over long distances and storeable over long time. The Power-to-Alu process converts renewable electricity into storable aluminum granules that can be transported and later be reconverted into energy during high-demand periods and at places with temporary lack of energy. This approach offers significant potential for balancing supply and demand and shows how stored energy could cover major winter deficits. Our results, based on the Antares simulator , show that a winter deficit of around 13 TWh in countries such as Switzerland could be offset by storing energy in 3 million tons of aluminum, indicating the potential to relieve the grid by supplying energy (Alu-to-Energy) from seasonal storage.
Keywords: renewable energy, aluminium storage, REVEAL, power-to-Alu, Alu-to-energy

INTRODUCTION

With the growth of the world population, both energy demand and the environmental impact of energy use are increasing. A primary goal is to reduce dependence on non-renewable energy sources such as coal, natural gas and nuclear power while increasing the share of renewable energy sources such as wind, solar and hydro in electricity generation. Many countries have been striving to migrate from fossil fuels to renewables to meet Paris Agreement targets, aiming for net-zero CO_2 by 2050 to limit global warming to 1.5°C. Europe's growing reliance on renewable energy sources, particularly solar and wind power, highlights the increasing need for long-term storage. This is because solar and wind power technologies have strong seasonal fluctuations, with solar energy peaking in summer and wind energy fluctuating throughout the year. As household heating demand is highest in winter, the seasonal surplus of solar energy doesn't align, creating a critical need for efficient storage solutions.

RESULTS

In our study, the Antares-Simulator modeling tool is used to predict future energy supply and demand on an hourly basis for several European countries. The results indicate that solar and wind energy generation will increase singificantly between 2030 and 2040. Wind power is expected to be the dominant renewable source in 2040 in Spain, Germany, the UK, France and the Netherlands, while solar will dominate in Italy, Switzerland and Slovenia. This is where seasonal energy storage, a promising solution proposed as a part of the REVEAL project, comes in. It works by capturing surplus electricity from renewables during periods of high-power generation and releasing it when supply is low. By converting surplus electricity into aluminum granules (Power-to-Alu) and then back into electricity (Alu-to-Energy), this approach can significantly improve the flexibility and resilience of the grid. To evaluate the potential, we analyzed the energy balance for selected countries to determine the potential for seasonal energy storage. The hourly fluctuations in energy production and demand for each country were flattened on a weekly basis. The resulting weekly surplus, where electricity production is higher than demand, represents the potential for aluminum granule production. For the REVEAL seasonal storage potential, we focus on periods where a positive electricity balance is evident for a subsequent number

of weeks. According to this positive electricity balance, we refer to MAX, as electricity available for storage during this period, while MIN corresponds to production without the need to store energy between weeks. Comparing the MAX available electricity with the total demand in 2040, Switzerland shows the highest potential among the selected countries after France (Figure 1)

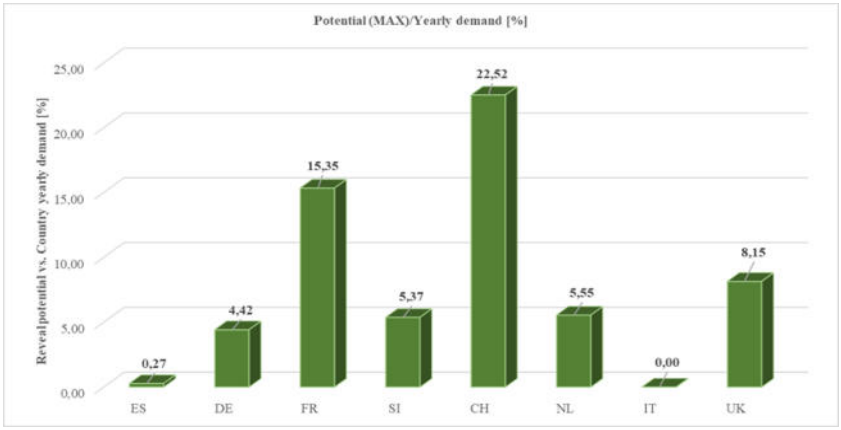
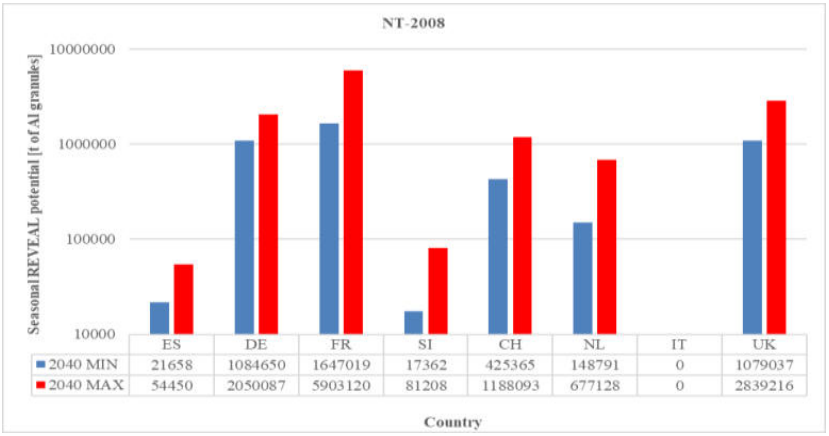


Fig.1: Amount of surplus MAX electricity per country in contrast to total demand in 2040

Our analysis has shown that this surplus electricity could indeed be used for seasonal storage. Based on the REVEAL project's technology, which requires 13.5 MWh of electricity to produce one tonne of aluminium granules, we have calculated the potential for aluminium production for the year 2040, taking into account both MIN and MAX energy availability (Figure 2). The results show that in countries such as France, 10 million tons of aluminium granulate could be produced with surplus electricity by 2040, which corresponds to an energy equivalent of 87 TWh. A high production potential is also expected in Germany, Switzerland, the Netherlands and the UK, which underlines the possibility of relieving the grid through energy supply from seasonal storage.



	ES	DE	FR	SI	CH	NL	IT	UK
2040 MIN	21658	1084650	1647019	17362	425365	148791	0	1079037
2040 MAX	54450	2050087	5903120	81208	1188093	677128	0	2839216

Fig. 2: Amount of Al granules (MIN and Max) that could be produced out of surplus electricity in 2040 for selected countries

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REFERENCES

[1] Software Presentation. https://Antares-Simulator.Org/Pages/Presentation-Du-Logiciel/1/.
[1] Vaziri Rad et al., (2013), Excess Electricity Problem in Off-Grid Hybrid Renewable Energy Systems.
[1] REVEAL. https://www.reveal-storage.eu/

CONFERENCE TOPIC

Next-Generation Technologies for Renewable Energy and Resource Efficiency.

METALS AS LONG TERM AND TRANSPORTABLE ENERGY STORAGE VECTORS – THE EU HORIZON PROJECT REVEAL-STORAGE

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SUMMARY:

The energy transition in Europe leads to a large-scale replacement of stored energy carriers in the form of fossil hydrocarbons or nuclear fuels with renewable electricity generation from wind and solar that do not comprise a storage function. Mismatches between electricity generation and energy use on o short time scale of hours or days can be tackled with load shifting and short-term storage solutions that are established products on the market. For long-term energy storage and for making renewable energy transportable, Renewable Metal Energy Carriers (ReMEC) have recently gained increasing interest. Aluminium as a storage vector has a number of advantages such as high availability, very high energy density, low cost, no need for cryogenic or pressurised vessels for storage, no toxicity and no explosion or fire risks. The main disadvantage is that the energy storage cycle based on aluminium has a lower Technology Readiness Level (TRL) than other candidates, with TRL 4 (of 9) reached at the end of the Horizon Europe REVEAL project.
Keywords: ReMEC, metal fuels, aluminium, iron, seasonal energy storage, power-to-X

INTRODUCTION:

The energy transition in Europe leads to a large-scale replacement of stored energy carriers in the form of fossil hydrocarbons or nuclear fuels with renewable electricity generation from wind and solar that do not comprise a storage function. Mismatches between electricity generation and energy use on o short time scale of hours or days can be tackled with load shifting and short-term storage solutions like electrochemical batteries or thermal energy storage that are economically viable and established products on the market. However, when it comes to seasonal mismatch between summer and winter, the choices are few and most technologies are either costly (e.g. eFuels) not scalable (e.g. large hydro-dams in the alps facing societal challenges) and/or restricted geographically (e.g. pit thermal energy storage that need to be connected to district heating). A new option for seasonal and transportable energy storage with high energy density that has emerged in recent years are Renewable Metal Energy Carriers (ReMEC): they provide high energy density, are easy to transport and store, do not need pressurised or cooled vessels, and are neither toxic nor flammable or explosive as long as they are not in the form of powders. ReMEC concepts are based on a charging process that removes oxygen from a metal-oxide, which requires large amounts of energy. Most of the energy required for this process is not lost, but stored chemically in the elementary metal. The metal can be transported over long distances and stored as long as desired without loss, and the energy can be released by oxidation of the metal. For the charging or metal-oxide reduction process as well as for the discharging or oxidation of the metal, different processes and chemical reactions are possible, as shown in Fig. 1. Aluminium (Al) and iron (Fe) are the most promising candidates for this application, with high availability and abundancy in the earth's crust, low cost, favourable properties concerning reactions and

toxicity of safety, and high energy storage densities of 23.4 MWh/m^3 (Al) and 16.1 MWh/m^3 (Fe) on a volumetric (solid block) base and 7.8 kWh/kg (Al) and 2.05 kWh/kg (Fe) on a gravimetric base [1], [2], [3]

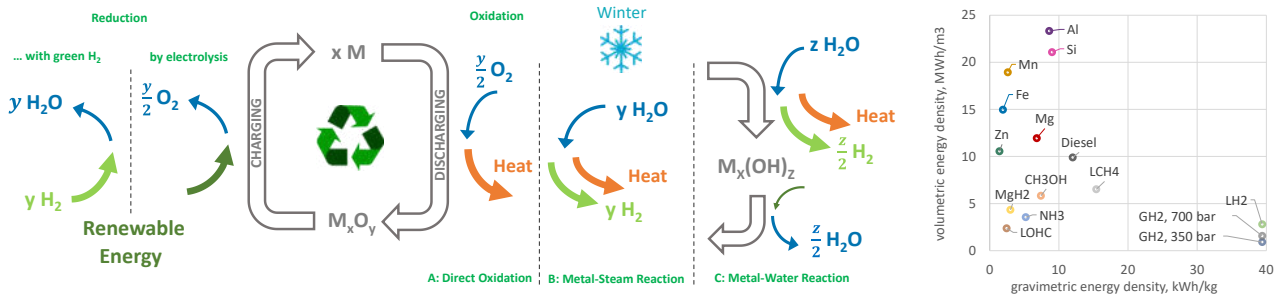


Fig. 1: Left: The charging and discharging processes of Renewable Metal Energy Carriers (ReMEC); M = Metal; Right: Volumetric and gravimetric energy densities of metal fuels compared to other chemical energy carriers, based on higher heating value (HHV) [1].

THE EU HORIZON REVEAL PROJECT

Within the EU Horizon Europe project REVEAL (www.reveal-storage.eu, 2022 - 2026) a consortium of nine partners from seven countries developed an energy storage cycle based on aluminium [4]. The aluminium is produced from its oxide by inert anode electrolysis (charging process, see contribution of Haller et al. at ISEC and [5]), then casted into granular form, transported to the point of use and discharged by oxidation with water as an oxidant. Two different paths of discharging have been tested: low-temperature metal water reaction (see contribution of Miren Agote-Aran et al. at ISEC and [6]) and the high temperature metal steam reaction (see contribution of Nigel Van De Velde et al. at ISEC). While details about the different steps of charging, discharging, prospective cost and LCA of the process can be found in single contributions to the ISEC 2026 conference (Willems et al., Drinčić et al., Hüppi et al.), this paper will give an overview of the whole energy storage cycle and the REVEAL process.

CONCLUSIONS

Metals, and in particular aluminium, can be used for storing renewable energy over long times and making it transportable. Aluminium as a storage vector has a number of advantages such as high availability, very high energy density, low cost, no need for cryogenic or pressurised vessels for storage, no toxicity and no explosion or fire risks. The main disadvantage is that the energy storage cycle based on aluminium has a lower Technology Readiness Level (TRL) than other candidates, with TRL 4 (of 9) reached at the end of the REVEAL project.

REFERENCES

[1] Y. I. Baeuerle, M. Y. HALLER, und M. Troxler, „PeakMetal - Covering Winter Peaks of Heat and Electricity Demand by “Renewable Metal Fuels”“, SPF Institut für Solartechnik , OST Ostschweizer Fachhochschule, Final report SI/502545-01, Juli 2024.

[2] J. M. Bergthorson, „Recyclable metal fuels for clean and compact zero-carbon power“, *Prog. Energy Combust. Sci.*, Bd. 68, S. 169–196, Sep. 2018, doi: 10.1016/j.pecs.2018.05.001.

[3] K. A. Trowell, S. Goroshin, D. L. Frost, und J. M. Bergthorson, „Aluminum and its role as a recyclable, sustainable carrier of renewable energy“, *Appl. Energy*, Bd. 275, S. 115112, Okt. 2020, doi: 10.1016/j.apenergy.2020.115112.

[4] M. Y. Haller, D. Carbonell, M. Dudita, D. Zenhäusern, und A. Häberle, „Seasonal energy storage in aluminium for 100 percent solar heat and electricity supply“, *Energy Convers. Manag. X*, Bd. 5, S. 100017, Jan. 2020, doi: 10.1016/j.ecmx.2019.100017.

[5] K. Singh, G. Gunnarsson, J. H. Magnusson, G. M. Haarberg, und G. Saevarsdottir, „Performance Evaluation of Low-Temperature KF-NaF-AlF3 Electrolytes for Aluminum Electrolysis Using Vertical Inert Cu–Ni–Fe Alloy Anodes“, *J. Electrochem. Soc.*, Bd. 170, Nr. 11, S. 113507, Nov. 2023, doi: 10.1149/1945-7111/ad0bae.

[6] M. Agote-Arán, B. Welte, R. Freeman, N. Mutti, M. Haller, und A. Heel, „Al6060 cut wire granules for Al-water reaction: Evaluation of reaction conditions and granule treatments“, *Int. J. Hydrog. Energy*, Bd. 117, S. 430–441, Apr. 2025, doi: 10.1016/j.ijhydene.2025.03.117.

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CONFERENCE TOPIC

Next-Generation Technologies for Renewable Energy and Resource Efficiency

POWER-TO-ALU – THE PROCESS OF STORING RENEWABLE ELECTRICITY IN ALUMINIUM WITHOUT CO2 EMISSIONS

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SUMMARY:

Renewable Metal Energy Carriers (ReMEC) have recently gained increasing interest. Aluminium as a storage vector has a number of advantages such as high availability, very high energy density, low cost, no need for cryogenic or pressurized vessels for storage, no toxicity and no explosion or fire risks. A pre-requisit for using aluminium as a ReMEC is a process for the production of aluminium from its oxide that does not emit CO2, i.e. a process that uses inert anodes instead of carbon anodes for aluminium electrolysis. An inert anode process has been developed at IceTec / Teaknisetur together with Arctus Aluminium Ltd and was demonstrated in a 500 Ampère cell at 800 °C producing several kg of Al per day with vertical electrodes and wetted cathodes. Stable operation, high efficiency, high aluminium purity and low anode wear rate were confirmed for this process.
Keywords: ReMeC, metal fuels, aluminium, seasonal energy storage, power-to-X, inert anodes, electrolysis

INTRODUCTION:

A new option for seasonal and transportable energy storage with high energy density that has emerged in recent years are Renewable Metal Energy Carriers (ReMEC): they provide high energy density, are easy to transport and store, do not need pressurized or cooled vessels, and are neither toxic nor flammable or explosive as long as they are not in the form of powders. Aluminium (Al) is one of the favourite metals for the use as a ReMEC, with high availability and abundancy in the earth's crust, low cost, favourable properties concerning reactions and toxicity of safety, and high energy storage densities of 23.4 MWh/m^3 on a volumetric (solid block) base and 8.7 kWh/kg (Al) on a gravimetric base [1], [2], [3]. Crucial factors for using Al as a ReMEC are:

1. A clean charging process (Power-to-Alu) that relies only on renewable electricity and emits no CO_2
2. The casting of the produced Al into a form that can be transported and used like a "fuel"
3. The Discharging (Alu-to-Energy) that releases the chemically stored energy for end-use
4. The closing of the material cycle by re-using the oxidized Al to produce new aluminium ReMEC again.

In this contribution, we highlight the demonstration of an efficient and CO_2-emission free process of reduction of aluminium oxide (alumina) to aluminium that is the first pre-requisit for using Al as a ReMEC.

THE INERT ANODE PROCESS IN COMPARISON TO TRADITIONAL HALL-HEROULT

The traditional process that is used to reduce alumina (Al_2O_3) to Al is a molten salt electrolysis where alumina is dissolved in molten cryolite and a carbon anodes is used that acts not only as anode but also as the reducing agent, i.e. the oxygen of the alumina ends up combining with the carbon of the anodes and is emitted as CO_2. This process typically is carried out at temperatures of roughly 960 °C and is also known, according to the names of its inventors, as the Hall-Héroult (HH) process, whose total chemical equation of the anode and cathode processes combined is $2\,Al_2O_3 + 3\,C \rightarrow 4\,Al + 3\,CO_{2(g)}$. The energy used in production of aluminium in HH cells comes from two sources, electric energy for electrolysis and thermal energy from reaction of carbon anodes

to CO_2. European producers use about 14.4 MWh/tonne Al of electric energy for electrolysis, while the thermal energy input from the reaction of carbon anodes is about 3.9 kWh/kg Al [4]. CO_2 emissions from the process are about 1.5 kg/kg Al, accompanied with emissions of other greenhouse gases like fluorocarbons. Therefore, for the development of a carbon-neutral energy storage cycle based on Al, inert anodes are used for the production of Al from alumina in new developed inert anode cells where oxygen is released instead of CO_2 and the formation of fluorocarbons is not possible: $2\ Al_2O_3 \rightarrow 4\ Al + 3\ O_{2(g)}$.

An inert anode process for the production of Al, developed at IceTec / Teaknisetur together with Arctus Aluminium Ltd, takes place at temperatures around 800 °C [5]. The process was demonstrated in a 400 Ampère cell producing several kg of Al per day with vertical electrodes and wetted cathodes, and was operated for several days. During operation, it was possible to reduce the anode-cathode distance, thereby reducing cell voltage to <4.0 V and improving energy efficiency. Energy consumption in the (not self-heated) cell was as low as 13.7 kWh per tonne of Al produced. Thus, the process reached an efficiency of 63.5% with respect of the energy stored in aluminium according to the enthalpy of its oxidation reaction, if only electricity input is considered, i.e. it is assumed that the external heating did not contribute substantially to the reaction itself. Scaling up to larger, self-heated cells will provide evidence of the full efficiency potential under real application. Purity of the Al was above 99.4%, and anode ware rate dropped after initial higher value to < 3 mm/yr.



Fig. 1: The inert anode cell setup at IceTec / Arctus Aluminium, and anodes after one of the test runs.

CONCLUSIONS

It was confirmed that Al production from its oxide can be achieved with inert anodes in a stable process at lab scale conditions that emits no CO_2 but O_2 instead in a process that takes place at 800 °C and 4 Volt cell potential, 400 Ampère current. Efficiency, Al purity and anode wear rate are in the desired range, and several kg of Al can be produced per day with this setup. Further development will deal with up-scaling, changing for a self-heated system, and the durability of the cell walls and materials in contact with the off-gases.

REFERENCES

[1] Y. I. Baeuerle, M. Y. HALLER, und M. Troxler, „PeakMetal - Covering Winter Peaks of Heat and Electricity Demand by "Renewable Metal Fuels"", SPF Institut für Solartechnik , OST Ostschweizer Fachhochschule, Final report SI/502545-01, Juli 2024.

[2] J. M. Bergthorson, „Recyclable metal fuels for clean and compact zero-carbon power", *Prog. Energy Combust. Sci.*, Bd. 68, S. 169–196, Sep. 2018, doi: 10.1016/j.pecs.2018.05.001.

[3] K. A. Trowell, S. Goroshin, D. L. Frost, und J. M. Bergthorson, „Aluminum and its role as a recyclable, sustainable carrier of renewable energy", *Appl. Energy*, Bd. 275, S. 115112, Okt. 2020, doi: 10.1016/j.apenergy.2020.115112.

[4] R. J. A. Moya *u. a.*, *Energy efficiency and GHG emissions: Prospective scenarios for the aluminium industry*. in Joint Research Centre, Institute for Energy and Transport. Luxembourg, 2015. Zugegriffen: 11. September 2025. [Online]. Verfügbar unter: https://core.ac.uk/download/pdf/38630795.pdf

[5] K. Singh, G. Gunnarsson, J. H. Magnusson, G. M. Haarberg, und G. Saevarsdottir, „Performance Evaluation of Low-Temperature KF-NaF-AlF3 Electrolytes for Aluminum Electrolysis Using Vertical Inert Cu–Ni–Fe Alloy Anodes", *J. Electrochem. Soc.*, Bd. 170, Nr. 11, S. 113507, Nov. 2023, doi: 10.1149/1945-7111/ad0bae.

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CONFERENCE TOPIC

Next-Generation Technologies for Renewable Energy and Resource Efficiency

WE GOE(S) CIRCULAR - FROM VISION TO REALITY: THE HANDS-ON JOURNEY BUILDING REGENERATIVE BUSINESS IN PRACTICE

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SUMMARY

The importance of transitioning to sustainable energy systems and implementing a circular economy is emphasized, highlighting sewage sludge management as a key example due to its potential for renewable energy generation and phosphorus recovery. The case of Vienna's Wien Energie facility demonstrates how mono-incineration technology enables both energy production and the creation of clean sewage sludge ash for use in fertilizer manufacturing. This offers environmental and health benefits in comparison to manufacturing using primary raw materials. Significant challenges remain, including high investment costs, insufficient funding, limited market incentives, and outdated regulatory frameworks that hinder the large-scale adoption of circular business models.

INTRODUCTION

To preserve our planet for future generations, it is essential to transform our energy systems and to implement an efficient circular economy. In this context, the resource-adequate management of sewage sludge from urban wastewater treatment plants plays a vital role and can serve as a prime example for building sustainable paths towards a renewable society. As a continually generated societal by-product, sewage sludge contains valuable resources in the form of renewable energy (Ferrentino et al., 2023) and phosphorus (Amann et al., 2021), as well as harmful substances that require appropriate treatment (Fijalkowski et al., 2017). While the exploitation of the sludge energy potential will provide decarbonized heat (Brandstätter et al., 2025), the recovery of phosphorus for subsequent use in the fertilizer industry will ensure food safety for the European Union (Brownlie, et al., 2023).

USE-CASE – SEWAGE SLUDGE TREATMENT IN VIENNA, AUSTRIA

To meet recovery potentials and fulfill treatment requirements, a careful evaluation of existing technological solutions is required. Mono-incineration of sewage sludge in fluidized bed incinerators is a state-of-the-art technology that enables both energy recovery as well as the generation of a safe and valuable raw material for phosphorus recovery (namely, sewage sludge ash). Since 1979, Wien Energie has been active in the incineration of sewage sludge from urban wastewater (see waste-to-energy plant *Simmeringer Haide* in Fig. 1). While the practice up to date has been the landfilling of the resulting ash and co-incineration of other wastes with sewage sludge was beneficial, the drive to recover phosphorus from this ash led Wien Energie to the installation of sewage sludge dryers to allow for mono-incineration and the production of a clean ash for recycling. As one of the largest European facilities in the treatment of sewage sludge, it is seen as imperative that Wien Energie takes on the responsibility in leading this sector towards a renewable future by showcasing best practices for phosphorus recovery from sewage sludge ash. A key aspect to turning this vision into reality is the pooling of resources, i.e. sewage sludges and ashes from other treatment plants to increase the market presence of secondary raw materials production facilities, such as the one in Vienna. Another important driver is seen in the exploitation of the benefits of secondary raw materials in comparison to its competing primary materials. As an example, high

cadmium (Cd) concentrations in the raw material for mineral fertilizers – phosphate rock – have long been a concern of regulators in the European Union (Ballabio et al., 2023). In comparison, the use of sewage sludge ashes in fertilizer production can help lower these concentrations (see comparison of concentrations in Tab. 1), therefore acting as a potential pull factor for the use of this secondary raw material. Identifying secondary raw material advantages such as these are seen as essential to bring innovation to life.

CHALLENGES

Circular business models operate in a difficult investment landscape. Technologies often require high initial investments (in infrastructure, technology, and personnel) and investment incentives can be insufficient. Furthermore, tapping into existing and well-established markets is challenging, and short-term revenue potential is limited. Subsidies and tax incentives can thus support the establishment of a business framework for sustainable, circular products from sewage sludge recycling. Further, an expansion of funding and financing mechanisms for investments in the necessary infrastructure is needed. Another challenge is the lack of regulatory frameworks for circular systems. Current regulations primarily address linear systems and do not act sufficiently as a catalyst, leading in turn to a lack in planning security. Pull factors like market incentives for the incorporation of recycled products are missing to date.

Table 1: Typical composition of sewage sludge ashes (Adam and Krüger, 2014) in comparison to phosphate rock (Kratz, Schick and Schnug, 2016) and legal limits for mineral P fertilizers in the EU (Regulation (EU) 2019/1009)

ELEMENT	UNIT	SEWAGE SLUDGE ASH	PHOSPHATE ROCK	LEGAL LIMITS
Al	%	3.4 – 11	0.2 – 0.5	
Ca	%	7.8 – 13	33	
Fe	%	2.4 – 17	0,2 – 7	
P	%	8.9 – 12	13 – 14	
As	mg kg^{-1}	12 – 54	5.0 – 14	40
Cd	mg Cd kg^{-1} P_2O_5	11 – 20	37 – 90	60
Cr	mg kg^{-1}	95 – 330	90 – 150	400
Cu	mg kg^{-1}	690 – 2100	15 – 31	600
Hg	mg kg^{-1}	0.25 – 1.1	–	1
Ni	mg kg^{-1}	47 – 100	21 – 41	100
Pb	mg kg^{-1}	100 – 280	3.8 – 15	120
U	mg kg^{-1}	3.2 – 11	23 – 87	
V	mg kg^{-1}	34 – 75	LOQ – 110	
Zn	mg kg^{-1}	2300 – 3400	110 – 430	1500



Fig. 1: Aerial view of the waste-to-energy plant Simmeringer Haide in 1110, Vienna, Austria (Source: Wien Energie)

REFERENCES

Adam, C. and Krüger, O. (2014). Monitoring von Klärschlammmonoverbrennungsaschen hinsichtlich ihrer Zusammensetzung zur Ermittlung ihrer Rohstoffrückgewinnungspotentiale und zur Erstellung von Referenzmaterial für die Überwachungsanalytik. Umweltbundesamt. TEXTE 49/2014. Dessau-Roßlau, 2014.

Amann, A., Weber, N., Krampe, J., Rechberger, H., Zoboli, O., & Zessner, M. (2021). Operation and Performance of Austrian Wastewater and Sewage Sludge Treatment as a Basis for Resource Optimization. *Water*, *13*(21), 2998. https://doi.org/10.3390/w13212998.

Ballabio, C., Jones, A., Montanarella, L. and Toth, G. (2023). Cadmium in the soils of the EU, EUR 28525 EN, Publications Office of the European Union, Luxembourg, 2023, https://doi:10.2760/635857.

Brandstätter, G., Fürsatz, K., Long, A., Hannl, T. K., & Schubert, T. (2025). Exploring the Potential of Sewage Sludge for Gasification and Resource Recovery: A Review. *Environmental Technology & Innovation*, 104346.

Brownlie, W.J.; Alexander, P., Cordell, D.; Maslin, M.; Metson, G.S.; Sutton, M.A.; Spears, B.M. (2023) National Phosphorus Planning for Food and Environmental Security, *Current Opinion in Biotechnology* 2024, 90:103226, https://doi.org/10.1016/j.copbio.2024.103226.

Ferrentino, R., Langone, M., Fiori, L., & Andreottola, G. (2023). Full-Scale Sewage Sludge Reduction Technologies: A Review with a Focus on Energy Consumption. *Water, 15*(4), 615. https://doi.org/10.3390/w15040615.

Fijalkowski, K.; Rorat, A.; Grobelak, A.; Kacprzak, M. (2017). The Presence of Contaminations in Sewage Sludge – The Current Situation, *J. Environ. Manag., 203(3)*, p. 1126-1136. https://doi.org/10.1016/j.jenvman.2017.05.068.

Kratz, S., Schick, J., & Schnug, E. (2016). Trace elements in rock phosphates and P containing mineral and organo-mineral fertilizers sold in Germany. *Science of the Total Environment*, *542*, 1013-1019.

Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
1.03. Circular Economy Strategies for the Energy Transition

AN OVERVIEW OF THE NETWORKING POTENTIAL OF DHC TEST FACILITIES

Edmund Widl[1], Anna Marie Cadenbach[2], Kai Heussen[3], Senne Van Minnebruggen[4], Cosima Wörle[5], Michele Tunzi[3], Jad Al Koussa[6], Nermina Abdurahmanovic[2], Mohd Basit Wani[7]

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SUMMARY

We highlight the importance of R&D infrastructure for developing future district heating and cooling (DHC) systems, emphasizing the challenges of limited laboratory resources. Recent advances in ICT enable the networking of geographically separated labs, allowing integration of hardware and simulations across thermal and electrical domains. Proof-of-concept studies demonstrate successful remote lab coupling for DHC and hybrid energy networks. Several innovative use cases are presented, including optimizing building-to-substation connections, studying consumer-side regulation, analysing faults in DHC systems, and validating power-hardware-in-the-loop (PHIL) systems. These approaches show the value of combining different infrastructures and suggest broader stakeholder benefits beyond academia.

Keywords: Future DHC Solutions, R&D Infrastructure, Remote Laboratory Integration, Sector Coupling

INTRODUCTION

Adequate research infrastructure is a key requisite for the development of future DHC systems. Unfortunately, only a limited number of (research) institutions have the resources to adequately cover all relevant aspects in a controlled laboratory environment. A relevant example is the experimental evaluation of sector coupling applications, where DHC systems can provide flexibility as a service to other parts of the energy system. Such applications require a laboratory environment covering both the thermal domain and the electrical domain on district scale, a combination that is rare in practice.

In recent years, however, there have been several essential developments that can help overcome this situation in a cost-efficient way. Innovative ICT solutions can connect geographically separated lab infrastructures, relying on dedicated middleware platforms, automation tools as well as distributed and secure deployment solutions.

This work provides a review of proof-of-concept case studies where hardware from test facilities and simulations have been digitally integrated for the experimental investigation of DHC systems. Based on this overview of the technical possibilities, a collection of innovative use cases for this type of networking of test facilities is provided.

PROOF-OF-CONCEPT CASE STUDIES

The coupling of remote labs has so far been used mostly for the electrical domain, but can just as well be applied to DHC applications and hybrid networks. The proof-of-concept for the underlying technologies has been given by studies that focussed on hardware-in-the-loop testbeds for thermal systems. For instance, Molitor et al.

demonstrated the coupling of a CHP and heat pump to real-time simulators of thermal and electrical loads. Another example was provided by Schneider at al., who demonstrated the coupling of a hydraulic loop including a pump with a simulated building. Recently, Frison et al. showed how to use similar technologies together with an appropriate IT infrastructure to distribute a district heating experiment across multiple remote laboratories.

USE CASES FOR NETWORKING OF TEST FACILITIES

The following use cases briefly illustrate the added value of combining different types of research infrastructure against the background of challenges related to DHC and sector coupling:

- **Bridging end-user heating systems with district heating substations**: This use case focuses on optimizing operations and generating robust data despite limited digitalization in buildings. It integrates a lab replicating an apartment building and a substation lab equipped with heat exchangers, storage tanks, and circulation systems.
- **Investigating consumer-side regulation in district heating networks**: This use case explores the relationship between user demand and network impacts by comparing lab experiments with real-world consumption data. It combines in-situ measurements in residential buildings with a hardware-in-the-loop setup and historical utility data.
- **Fault analysis in district heating systems**: This use case enables the study of fault propagation, system stability, and the testing of new control strategies. It also investigates consumer flexibility and highlights challenges in software compatibility and interface dynamics. It combines lab infrastructure for DHC network testing with a testbench for heat interface units.
- **Validation of power-hardware-in-the-loop (PHIL) systems**: This use case integrates real hardware with simulation tools to test field-level control strategies and energy management systems under realistic conditions. It combines lab infrastructure for DHC network testing with real-time simulations and a load emulator for replicating heat pump behaviour.

In addition to the use cases, a compilation of stakeholders that would benefit from networked laboratory infrastructure outside of academia will be derived.

REFERENCES

Molitor, C., et al. (2013), Multiphysics test bed for renewable energy systems in smart homes, IEEE Transactions on Industrial Electronics, vol. 60, no. 3, pp. 1235–1248.

Schneider, G., et al. (2015), Hardware-in-the-Loop-Simulation of a Building Energy and Control System to Investigate Circulating Pump Control Using Modelica, Proc. of the 11th International Modelica Conference.

Frison, L., et al. (2024), Presentation of a distributed testing infrastructure for joint experiments across multiple remote laboratories for robust development of new district heating concepts, Smart Energy, vol. 15.

CONFERENCE TOPIC

This abstract refers to the following conference topic: 1.08. Future District Heating and Cooling Solutions

CLIFF: THE CLIMATE FIREFIGHTERS INITIATIVE (WORKING TITLE)

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SUMMARY

Despite global commitments and risk asymmetry, we are not on track to meet the Paris Agreement goals. Every 1/10 degree of global warming increases the risk of an uncomfortable or even dangerous future for everyone, while timely action on Paris- and 2 °C programs will increase wealth (by a total of app. $85-107 trillion [Barrage 2024]) and leads to low risk.

The built environment - construction, operation, and demolition of buildings - remains a major, yet under-addressed, source of greenhouse gas emissions. Key barriers are fragmented, unreliable information that hinder unified, effective climate action. CLIFF offers a unique framework to extinguish the “fires” blocking climate progress with cost-effective measures. CLIFF enables a sustainably climate-neutral world based on facts and unbiased information that reflect reality as it is. It brings assembled and structured insights from current science to practice and fills knowledge gaps effectively and scientifically unbiased.

CLIFF evolved from a spontaneous discussion at ISEC 2024. The concept was further developed ever since. The name is a working title that might be changed for the final paper and presentation. For taking off, the initiative is now reaching out to motivate involvement and gather the power and expertise from experts all over the world.

The contribution presents the network idea of a voluntary international climate protection fire brigade, in which initiatives, researchers, and foundations, among others, work together. It describes how to join the overarching framework for evidence-based action towards climate neutrality, providing clarity and tools for effective climate action!

Keywords: climate change, buildings, construction, overarching network, evidence-based climate action

VISION AND MISSION

CLIFF supports the well-being of all beings on planet Earth by enabling concerted, sustainable action to stabilize the climate. A stable climate is not an end in itself, but a precondition for thriving societies, resilient ecosystems, and a just future. Actions towards climate stability are low risk, while inaction risks the wellbeing of humanity as a species for centuries to come. CLIFF bridges the gap between science and real-world solutions by providing unbiased, actionable insights, and by fostering a coherent framework that integrates climate stability with all other relevant dimensions of sustainability.

As a first step, the CLIFF Initiative focuses on the built environment—one of the largest sources of greenhouse gas emissions. From construction and operation to demolition and disposal, buildings and infrastructure account for a significant share of climate impacts. By addressing these challenges comprehensively, CLIFF aims to transform the built environment into a driver of climate resilience and sustainable development.

SOLUTION

CLIFF follows a unique approach. The umbrella structure unites fragmented efforts and thereby ensures that no critical knowledge is overlooked. Furthermore, by at first focusing on one sector – the built environment – one of the most significant and cost-effective levers for emission reduction is targeted.

The CLIFF framework to extinguish the "fires" blocking climate progress includes:

- Integration: CLIFF maps the full landscape of climate knowledge, identifying gaps ("missing puzzle pieces") critical to achieving climate targets.
- Research: CLIFF commissions targeted studies to fill these gaps with reliable, actionable data.
- Guidance: CLIFF translates findings into practical guidance.

The first step to realizing the vision of an evidence based sustainable world is to identify the gaps between current knowledge and practices. And especially those required to reach the goals of the Paris Agreement. An analogy is that reaching climate targets is a puzzle. CLIFF identifies puzzle pieces, where they fit and what is missing. The missing parts are then researched.
In a second step, research is proposed to fill the gaps with reliable and comprehensive information.
A third step entails conducting the required research and integrating its findings into a continuously improving and updated guidance system for decision- and policymakers and industry leaders.
Like any firefighter initiative, the idea is to keep the CLIFF initiative ongoing until the fire is extinguished, which means the target of climate sustainability is reached.

STATUS QUO

The initiative's early status will be presented, including preliminary work on open digital methods and on networking to overcome disinformation through clear and neutral CLIFF guidance.

CLIFF - Idea of a European Voluntary
Climate Fire Fighter Initiative

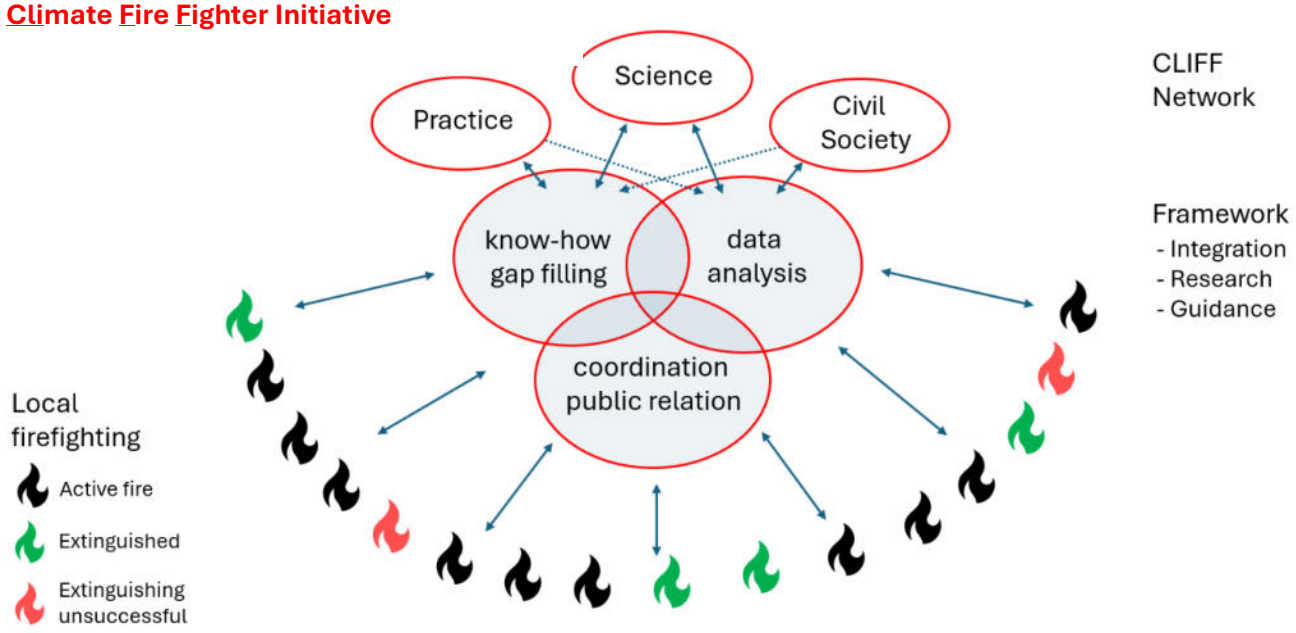


Fig. 1: Preliminary considerations of the CLIFF umbrella structure, starting in Europe

Examples will be given of how independent and open data can support science, industry, and decision-makers from civil society and politics. The status of organizational preparations for specific “firefighting operations”, e.g., with foundations, will be explained.

CALL TO ACTION

The successful implementation of the CLIFF Initiative requires a combination of interdisciplinary cooperation and research, promotion of best practices, education, training, and advocacy. Experts from diverse disciplines are invited to join the initiative, bring in their expertise, and develop CLIFF as an umbrella structure as well as collaborate in research projects to fill the identified gaps.
CLIFF initiates research to transfer the vulnerable Paris target to embedded targets that include widely accepted dimensions of sustainability and consider the self-interest of different groups.
Support the CLIFF Initiative as an overarching framework for evidence-based action towards sustainable climate neutrality, providing clarity and tools for effective climate action. Thereby, you empower decision-makers with the clarity and tools they need for effective climate action that is the foundation of a sustainable and just future for them, their children and everyone else on planet Earth.

CONFERENCE TOPIC

“Just and inclusive mechanism for the energy transition” (2.03)

LITERATURE

[Barrage 2024] Lint Barrage, William Nordhaus, Policies, projections, and the social cost of carbon: Results from the DICE-2023 model, PNAS 2024 Vol. 121 No. 13 e2312030121, Download 2025-08-21 https://www.pnas.org by 74.72.234.72

MULTI-CRITERIA DECISION ANALYSIS OF ENERGY STORAGE SYSTEMS FOR A PV-MINI-GRID IN SUB-SAHARAN AFRICA

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SUMMARY

In many regions of Sub-Saharan Africa, a comprehensive electricity grid is not available and reliability and safety of the available grid is not guaranteed. Therefore, Mini-Grids powered by photovoltaics can be an alternative solution to ensure a stable electricity supply. Yet, the intermittency of solar energy requires efficient energy storage technologies. To identify suitable options, this study applies a Multi-Criteria Decision Analysis using the Analytic Hierarchy Process to systematically compare lithium-ion batteries, hydrogen-based storage, and vanadium redox flow batteries in terms of technical and economic performance as well as ecological impact indicators. Criteria such as energy efficiency, lifetime, GHG emissions, safety, and resource availability are considered to capture the sustainability requirements of energy storage. The evaluation combines real operational data (e.g. installed power and capacity) from a mini-grid in Ghana with insights from the literature. Results illustrate how a multi-criteria approach can support the design of more sustainable renewable energy systems.

INTRODUCTION

Reliable electricity supply is essential for sustainable development in Sub-Saharan Africa, where in 2023 about 565 million people still lacked basic access [1]. In off-grid regions, storage systems are key to balancing intermittent energy supply from renewable sources such as photovoltaics (PV). This study applies a Multi-Criteria Decision Analysis (MCDA) using the Analytic Hierarchy Process (AHP) [2] to compare lithium-ion-batteries (LIB), vanadium redox flow batteries (VRFB), and hydrogen-based (H2) storage for a PV mini-grid in Ghana (see Section 3 for details). While storage technologies have been studied individually from technical, economic, or ecological perspectives, systematic integrative assessments across all sustainability dimensions remain scarce. Accordingly, the following research question is addressed: *How can the application of Multi-Criteria Decision Analysis support the comparative assessment of the sustainability of different energy storage technologies in PV mini-grid systems in Ghana?*

USE CASE

The use case is a PV mini-grid in Ghana, composed of interconnected rooftop solar panels. To maintain a stable electricity supply despite fluctuating PV energy generation, the system combines LIBs with a hydrogen-based storage unit. In our study, sustainability assessment is based on the triple-bottom-line model [3], encompassing ecological, economic, and social dimensions, and complemented by technological performance. The ecological dimension is represented by greenhouse gas (GHG) emissions and resource availability; the social dimension by safety; and the economic dimension by the levelized cost of storage (LCOS). Technological performance is assessed through energy efficiency, lifetime, self-discharge, and energy density. The selection of these criteria reflects both sustainability considerations and the technical characteristics of the system.

METHODS

Assessing the sustainability of products or systems requires integrating diverse environmental, economic, and social indicators. These can be derived from established methods such as Life Cycle Assessment (LCA), Life Cycle Costing (LCC), or Social LCA (SLCA). Since such indicators often differ in scale, unit, and relevance, MCDA offers a structured way to aggregate them into a comprehensive evaluation [4]. In this study, AHP [5] is applied to structure the decision-making, assign weights to each criterion, and rank the alternative energy storage technologies: LIB, VRFB, and H2-based storage systems (see Section 3 for criteria). Building on an extensive literature review, the required indicator values were compiled and complemented by expert-based weighting to reflect the priorities of sustainable energy supply in the context of the use case. The weighting was derived from pairwise comparison conducted with the Saaty scale [5]. The resulting evaluation was performed with an MS Excel-based MCDA tool, resulting in a decision model applicable to other regional or technological contexts.

PRELIMINARY RESULTS AND DISCUSSION

Preliminary results reveal distinct strengths and trade-offs among the evaluated storage technologies, underscoring the complexity of identifying one single best option in terms of sustainability. The results indicate that LIBs achieve the best score, while VFRBs and H2-based storage systems perform slightly worse (refer to Figure 1). A more detailed examination of the individual criteria, however, reveals substantial differences (refer to Figure 2). The H2-based system, despite ranking lowest overall, demonstrates clear advantages in terms of lifetime, whereas the VRFB achieves the most favorable results in the highest-weighted criterion of GHG emissions. These findings highlight the need for a nuanced interpretation of the results, emphasizing the importance of breaking down and contextualizing the performance of each technology across individual criteria.

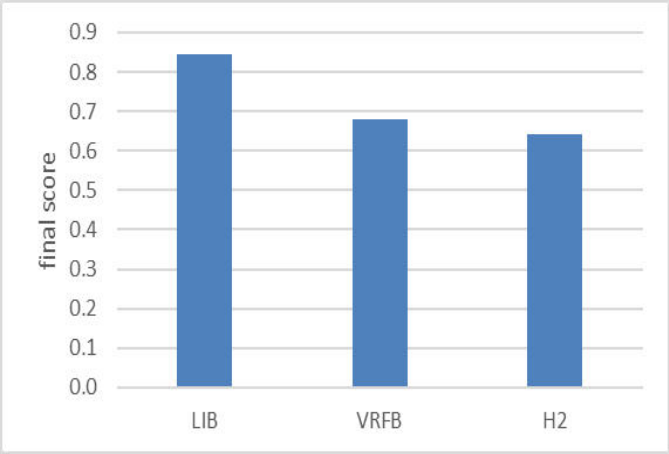


FIGURE 1: FINAL SCORE OF ASSESSED ALTERNATIVES. LIB = LITHIUM-ION BATTERY, VRFB = VANADIUM REDOX FLOW BATTERY, H2 = HYDROGEN STORAGE SYSTEM.

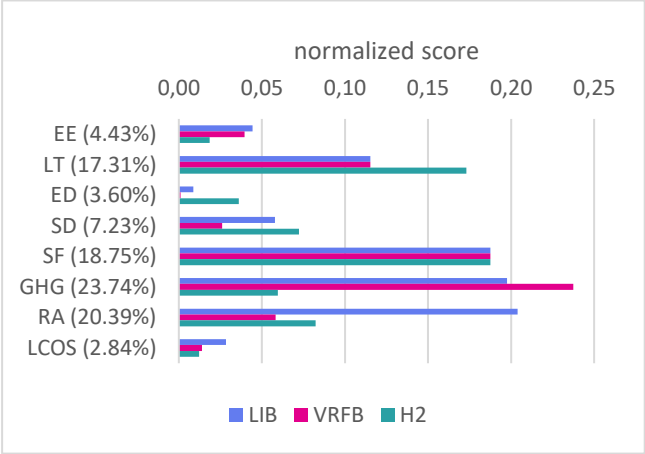


FIGURE 2: SCORING FOR EACH REGARDED CRITERION. THE VALUES IN ROUND BRACKETS REPRESENT THE WEIGHTINGS. EE = ENERGY EFFICIENCY, LT = LIFETIME, ED = ENERGY DENSITY, SD = SELF-DISCHARGE, SF = SAFETY, GHG = GREENHOUSE GAS EMISSIONS, RA = RESOURCE AVAILABILITY, LCOS = LEVELIZED COST OF STORAGE.

REFERENCES

[1] IEA, IRENA, UNSD, World Bank, and WHO, 'The Energy Progress Report'. World Bank, 2025. [Online]. Available: https://www.irena.org/Publications/2025/Jun/Tracking-SDG-7-The-Energy-Progress-Report-2025

[2] E. Mu and M. Pereyra-Rojas, *Practical Decision Making*. in SpringerBriefs in Operations Research. Cham: Springer International Publishing, 2017. doi: 10.1007/978-3-319-33861-3.

[3] H. Alhaddi, 'Triple Bottom Line and Sustainability: A Literature Review', *Bus. Manag. Stud.*, vol. 1, no. 2, p. 6, Apr. 2015, doi: 10.11114/bms.v1i2.752.
[4] L. Andes, T. Lützkendorf, B. Ströbele, J. Kopfmüller, and C. Rösch, 'Methodensammlung zur Nachhaltigkeitsbewertung Grundlagen, Indikatoren, Hilfsmittel', Karlsruher Institut für Technologie (KIT), 2019. doi: 10.5445/IR/1000128806.
[5] T. L. Saaty, 'How to make a decision: The analytic hierarchy process', *Eur. J. Oper. Res.*, vol. 48, no. 1, pp. 9–26, Sep. 1990, doi: 10.1016/0377-2217(90)90057-I.

CONFERENCE TOPIC

Our study affects the conference topic 1.16 (Transform Cities: Holistic Approaches to Sustainable Urban Energy) and with a focus on Sub-Saharan African it is related to the global south.

CONSTRUCTION AND VALIDATION OF A MODULAR PHOTOELECTROCHEMICAL CELL FOR SOLAR-TO-HYDROGEN CONVERSION

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SUMMARY

Achieving a sustainable energy economy requires efficient and scalable methods for renewable hydrogen generation. Photoelectrochemical (PEC) water splitting is a promising approach, directly converting solar energy into hydrogen. However, material instability, corrosion, and efficiency–durability trade-offs remain major areas for exploration. A PEC cell consists of a photoactive electrode, a counter electrode, and an electrolyte, with different possible configurations. In this study, a photoanode/electrochemical cathode setup was employed. To overcome the limitations of existing designs, a modular PEC cell was developed with mechanical stability, chemical resistance and flexible electrode integration. The prototype was successfully commissioned, hydrogen production was demonstrated, and hematite photoanodes were characterized.
Key-words: Photoelectrochemical cell, solar water splitting, cell design

INTRODUCTION

The transition towards a sustainable and carbon-neutral energy economy requires scalable and cost-effective solutions for renewable feedstocks and energy carriers. Hydrogen is seen as critical element in achieving global decarbonization targets. It can be bound in compounds such as ammonia and stored in gaseous or liquid form and can be used as a fuel, feedstock, or energy carrier in transport, industry, and power generation. (Marocco et al., 2023)·(Sikiru et al., 2024)
Despite its potential, the large-scale production of green hydrogen from renewable resources remains one of the central challenges. Photoelectrochemical (PEC) water splitting has emerged as one of the most promising technologies for the direct conversion of solar energy into hydrogen, combining light harvesting and electrolysis in one system. Nevertheless, the path toward practical implementation of PEC devices is not without significant challenges. Material stability remains a critical bottleneck, as many semiconductors corrode under acidic/alkaline media and illuminated conditions, leading to short device lifetimes. Achieving a balance between high efficiency and long-term durability continues to be an active area of research, often requiring catalyst integration, and advanced material engineering. (Qureshy and Dincer, 2020)·(Carver et al., 2012)

WORKING PRINCIPLE OF A PEC CELL

The central components of a PEC cell are the photoactive electrode (= photoelectrode), a counter electrode and the electrolyte. (Carver et al., 2012) It is acknowledged that there are multiple electrode configurations of a PEC cell; these can be constituted of a photoanode and an electrochemical cathode, or alternatively, a photocathode and an electrochemical anode. It is evident that an applied bias is required to facilitate the water splitting reaction. The third configuration under consideration is that of a PEC tandem cell, using a photoanode and a photocathode. This eliminates the need for a bias voltage. At the (photo)anode the oxygen evolution reaction (OER) and on the

(photo)cathode the hydrogen evolution reaction (HER) occurs. These configurations and the generation of electron-hole pairs are illustrated in Figure 1. (Tijent, Voss and Faqir, 2023)
In our study, a PEC cell consisting of a photoanode and an electrochemical cathode is used, Fig. 1 (b). The holes migrate to the semiconductor surface to drive the OER, while the electrons travel through the external circuit to the cathode to reduce protons to hydrogen.

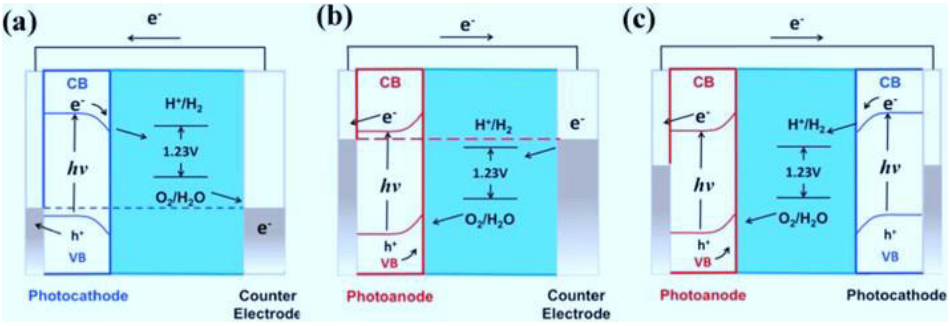


Fig. 1: Different electrode configurations of a PEC cell: photocathode and counter electrode (a), photoanode and counter electrode (b) and both, photoanode and photocathode in a PEC tandem cell (c). (Tijent, Voss and Faqir, 2023)

CELL DESIGN FOR PHOTOELECTROCHEMICAL WATER SPLITTING

Our work addresses these challenges by developing a modular PEC cell that combines mechanical stability, chemical resistance, flexibility in electrode integration, and optimized electrolyte flow. The motivation stems from the observation that existing cell designs often lack adaptability: they are optimized for specific electrode geometries, limited in their electrolyte compatibility, or difficult to assemble and operate in a reproducible way. To overcome these barriers, a new PEC cell concept was proposed, designed, and prototyped as part of this study. The PEC cell, which has been designed for this specific application, has been successfully commissioned, and green hydrogen has been produced. In this instance, a 3-electrode configuration was employed to electrochemically characterise a series of hematite photoanodes. The PEC cell is currently being upgraded with the objective of enabling its operation in pump mode. This will result in the capacity for clean gas separation.

REFERENCES

Carver, C., Ulissi, Z., Ong, C.K., Dennison, S., Kelsall, G.H. and Hellgardt, K., 2012. Modelling and development of photoelectrochemical reactor for H2 production. *International Journal of Hydrogen Energy*, [online] 37(3), pp.2911–2923. https://doi.org/10.1016/j.ijhydene.2011.07.012.

Marocco, P., Gandiglio, M., Audisio, D. and Santarelli, M., 2023. Assessment of the role of hydrogen to produce high-temperature heat in the steel industry. *Journal of Cleaner Production*, 388. https://doi.org/10.1016/j.jclepro.2023.135969.

Qureshy, A.M.M.I. and Dincer, I., 2020. A study on energy and fluid flows for a novel photoelectrochemical reactor developed for hydrogen production. *International Journal of Heat and Mass Transfer*, 163. https://doi.org/10.1016/j.ijheatmasstransfer.2020.120523.

Sikiru, S., Oladosu, T.L., Amosa, T.I., Olutoki, J.O., Ansari, M.N.M., Abioye, K.J., Rehman, Z.U. and Soleimani, H., 2024. Hydrogen-powered horizons: Transformative technologies in clean energy generation, distribution, and storage for sustainable innovation. *International Journal of Hydrogen Energy*, [online] 56, pp.1152–1182. https://doi.org/10.1016/j.ijhydene.2023.12.186.

Tijent, F.Z., Voss, P. and Faqir, M., 2023. Recent advances in InGaN nanowires for hydrogen production using photoelectrochemical water splitting. *Materials Today Energy*, [online] 33, p.101275. https://doi.org/10.1016/j.mtener.2023.101275.

CONFERENCE TOPIC

1.14. Solar-to-X Technologies for Fuels and Chemicals

ASSESSING DEEP RENOVATION EFFECTIVENESS THROUGH ENERGYPLUS SIMULATIONS VALIDATED BY MONITORING DATA: A RESIDENTIAL CASE STUDY

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SUMMARY

This study focuses on the deep renovation of a residential building in Amstetten, Austria. The renovation targets reductions in energy consumption and operational CO_2 emissions through architectural design optimization, building envelope upgrades using prefabricated elements mainly made of renewable materials, and an HVAC retrofit integrating ground-source heat pump (GSHP) and photovoltaic (PV) systems. The building energy model (BEM) is created using EnergyPlus, and its outputs are validated against monitoring data. Following validation, the pre- and post-renovation simulation results were compared to quantify the improvements. Preliminary simulation results indicate a 61% reduction in Energy Use Intensity (EUI), while summer monitoring showed zone air temperatures deviated by up to 9 °C from the simulations, possibly related to parameter settings for the ground heat exchanger, internal gains, and ventilation. This suggests the need for BEM modifications, which will be further validated through continued monitoring.
Keywords: Deep renovation, Renewable energy, free cooling, CCA, GSHP, EnergyPlus, BEM, BPS

INTRODUCTION

Buildings account for approximately 40% of energy consumption and 36% of greenhouse gas emissions in the EU, with over 75% of existing buildings being energy-inefficient and expected to remain in use until 2050 [1]. To achieve the EU's 2050 carbon neutrality target, deep renovations that could drastically reduce energy consumption are essential. However, the current renovation rate of 0.2% per year for renovations that enable at least a 60% energy saving is far from sufficient [2]. Therefore, there is a critical need to explore and validate effective renovation technologies and strategies to accelerate the adoption of deep renovations in existing old buildings.

Against this background, the subject of this study is a mixed-use residential and office building in Amstetten, Austria. The building underwent a deep renovation, including an architectural redesign, envelope upgrades using prefabricated elements, and a comprehensive retrofit of the energy system.

The building is equipped with vertical ground heat exchangers coupled with the soil, supplying floor radiant heating and domestic hot water through a GSHP system. In summer, the ground heat exchangers are directly connected to a Concrete Core Activation (CCA) implemented in a newly developed glued timber-concrete composite floor [3], as well as a ceiling cooling in the new top floor implemented as wood construction, enabling free cooling. Ventilation is provided by a unit equipped with a dual heat recovery system. In winter, sensible heat from the exhaust air is recovered and partly used to condition the supply air, while another portion is used to regenerate the geothermal probes through the brine loop. In summer, the relatively cool brine from the probes is used to precool the supply air, thereby reducing the cooling demand [4]. The electricity supply relies primarily on generation from rooftop PV panels combined with an electric energy storage and on the grid when insufficient energy is delivered (mainly in the winter months). In addition, the building is equipped with a monitoring system that records operational data of the equipment and zone conditions.

Building on this basis, the study quantitatively assesses the energy efficiency improvements achieved by the deep renovation based on building performance simulation (BPS) results. Additionally, monitoring data are used to validate the simulation results, thereby ensuring the accuracy of the BEM and enhancing the reliability of the renovation evaluation. Considering the advanced energy systems employed in the renovation, the study's methodology and findings provide a reference for future deep renovation projects in similar buildings.

METHDOLOGY

This study employs EnergyPlus as the BPS tool, with all required building and environmental data collected in accordance with its modeling specifications.

Basic building information, including building geometry, materials, wall constructions, and HVAC system details, is obtained through technical drawings and site surveys. Equipment operation and energy consumption data are collected through sensor monitoring and utility bills to support subsequent validation of the model.

The monitoring data cover: domestic hot water and thermal storage tank temperatures; supply and return water temperatures at heating/cooling terminals; the operating status of the ground heat exchanger and ground-source heat pump; air temperature and humidity in thermal zones; photovoltaic power generation, and some outdoor weather conditions. All data are recorded at 3-minute intervals to ensure sufficient temporal resolution to capture the system's operational characteristics accurately.

After compiling the basic information, the study proceeds to geometric modeling and energy system simplification. Since EnergyPlus lacks intuitive geometry modeling functions, Building Information Modeling (BIM) tool is used to define the geometry. In this study, 3D geometry information was generated in SketchUp and subsequently imported into EnergyPlus. This workflow improves modeling efficiency and also supports future geometry adjustments. In energy system modeling, reasonable equivalence assumptions for the HVAC system are adopted to ensure the physical consistency and logical validity of the complex BEM. This consistency relies on coherent model inputs, encompassing key aspects such as envelope properties, equipment specifications, internal loads and usage patterns, and environmental conditions. Proper BEM input and physical description are essential for maintaining the physical validity, integrity, and predictive reliability of the building energy model.

With the BEM inputs finalized, a trial simulation is conducted. The BEM is refined until it stabilizes and produces valid outputs. Once stabilized, the simulation results are validated against monitoring data through time-series analysis, using statistical metrics such as RMSE and NMBE to evaluate the accuracy of the BEM. Finally, the pre- and post-renovation simulation results are compared to quantify the effects of the renovation.

PRELIMINARY WORK AND RESULTS

Two initial BEMs were developed to represent the building pre- and post-renovation. A preliminary comparison of the simulation results indicates that total site energy use decreased by 37.8%, net source energy decreased by 39.5%, and electricity intensity dropped by 46.3% following the deep renovation.

Since March of this year, the building's monitoring system has operated continuously, generating data. Early comparison revealed deviations up to 9°C between monitored and simulated zone temperatures. These discrepancies may be associated with the parameter settings for the ground heat exchanger, internal gains, and ventilation, suggesting that BEMs need to be modified, particularly for the ground heat exchanger group. Data collection will continue, and accumulating long-term monitoring data over six to twelve months will enable more comprehensive validation of the simulation results.

REFERENCES

[1] Gepts, B., Nuyts, E., & Verbeeck, G. (2025). Where is the potential for deep (energy) renovations? A large-scale study of the renovation activities of Belgian households between 2018 and 2022. Energy and Buildings, 328, 115150. https://doi.org/10.1016/j.enbuild.2024.115150
[2] European Commission. (2020). A renovation wave for Europe: Greening our buildings, creating jobs, improving lives (COM(2020) 550 final). Publications Office of the European Union.
[3] Brosch, F., Riexinger, S., Braun, M., & Kromoser, B. (2025). From lab to field: Implementing adhesive bonded timber-concrete-composites ceilings – A pilot project. In World Conference on Timber Engineering 2025 (pp. 1250–1257). World Conference on Timber Engineering 2025. https://doi.org/10.52202/080513-0154
[4] Weider Wärmepumpen GmbH. (2025). GeoAir–Rückenwind durch gegenseitige Unterstützung. Retrieved September 12, 2025, from https://www.weider.co.at/de/waermepumpen/produkte/geoair

CONFERENCE TOPIC

Sustainable Renovation and Energy Retrofits

UNLOCKING VALUE WITH DECENTRALIZED, SECTOR-COUPLED ENERGY SYSTEMS

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SUMMARY

Rising energy costs, increasing market volatility, and growing regulatory pressure are creating major challenges for industrial and commercial enterprises. Energy is no longer just a cost factor – it has become a strategic driver of competitiveness. Companies are under pressure to make their energy use more transparent, efficient, and sustainable.
Decentralized sector-coupled energy systems offer a powerful solution. By intelligently connecting electricity, heating, cooling, mobility, and infrastructure, they unlock synergies that go far beyond traditional stand-alone measures. Photovoltaics, energy storage, heat pumps, charging infrastructure, and waste heat recovery only reach their full potential when combined in an integrated approach.
Our approach demonstrates how structured data collection, simulations, and scenario comparisons enable companies to design economically viable energy strategies. Based on realistic load profiles and ROI assessments, companies gain solid decision-making tools for future investments. This allows for both short-term cost savings and long-term resilience. Businesses benefit not only from reduced costs but also from planning security and compliance with regulations. By applying this methodology, we assume future energy system scenarios (e.g. 2030 and 2035) and derive the required adaptions to the energy system to achieve the best possible results.
What makes this approach unique is the balance of technical depth and practical relevance. Simulations and calculations make complex energy flows transparent. The result is a scalable blueprint that can be applied not only to a single site but also across multiple facilities and industries and even in temporary applications like construction sites.

INTRODUCTION

The energy supply of industrial and commercial enterprises is undergoing fundamental change. While in the past energy was seen as a reliable but interchangeable resource, in recent years it has evolved into a decisive factor for competitiveness.

Market Environment, Regulations and Challenges

Energy prices are increasingly volatile. Spot market prices have shown significant fluctuations between day and night, as well as across seasons. This volatility makes planning difficult and can quickly lead to substantial additional costs. At the same time, regulatory requirements are tightening under the European Green Deal, the Fit-for-55 package and the Clean Industrial Deal, companies must systematically measure and reduce CO_2 emissions. National funding schemes provide opportunities but are often complex and difficult to navigate. Industrial and commercial operations typically face high energy demand – for buildings (heating, cooling, lighting), production processes, and mobility (vehicle fleets). Current strategies are often limited to stand-alone measures, such as installing photovoltaics, exchanging heating systems, or electrifying a few vehicles. These isolated actions deliver only limited benefits, as they are not interconnected. The result: unused potential, low

self-consumption rates, little resilience against energy price or supply shocks, and even negative lock-in effects by adopting to a not beneficial energy system scenario.

The Role of Sector Coupling

Sector coupling systematically integrates electricity, heating/cooling, mobility, and processes. For example, surplus solar power can be used to charge batteries or heat storage, which in turn support production processes or power vehicle fleets. Such interconnections unlock efficiency gains that cannot be achieved by stand-alone solutions. By increasing the electrification of different consumers the overall energy demand will be reduced significantly.

CONCEPT & METHODOLOGY

Our approach combines technical simulations with clear economic evaluation. The goal is to provide companies with a robust basis for decision-making – moving away from gut feeling towards data-driven energy strategies.



Figure 1: The Energy System: Energy Input, Storage and Consumption

Step 1: Data Collection & Transparency

The process begins with capturing all relevant data: electricity and heat demand, load profiles, building information, and fleet mobility data. These inputs are modeled to simulate energy flows over a full year, in 15-minute intervals. This makes peak loads and untapped potentials visible.

Step 2: Simulation & Scenario Development for the future Energy System

Different system configurations are designed based on technically and economically feasible future energy system solutions (e.g. 2030 and 2035) regarding the energy input, storage and consumption including:

- PV and other options of own electricity production
- Battery storage
- Heat pumps and thermal storage for coupling electricity and heat.
- Charging infrastructure for fleets.
- Waste heat recovery from production processes.
- Spot market optimization to buy or sell energy at the most favorable times.

Each scenario is assessed in terms of efficiency, degree of self-sufficiency, OPEX, CAPEX, ROI, and CO_2 reduction. Importantly, the analysis is conducted vendor-independent, ensuring that the technically and economically optimal solution is identified for each company.

Step 3: Scenario Comparison & Recommendations
Simulation results are compared transparently: Which configuration delivers the highest savings? Which scenario maximizes CO_2 reduction? Which mix of measures is both technically feasible and financially sound? Based on these results, we provide strategic recommendations tailored to each business.

Step 4: Roadmap & Implementation
Beyond analysis, a practical roadmap is developed – prioritizing short-, mid-, and long-term measures. Investment budgets, subsidies, and structural conditions are considered to create a realistic, actionable plan.

Customer Value

- Transparency of current energy flows and potentials.
- Reliable ROI-driven decision-making tools.
- Economically viable, regulation-compliant solutions.
- Vendor independence ensures objective recommendations.
- A scalable blueprint transferable across sites and industries.

PRATICAL CASES AND RESULTS

We demonstrate our approach using practical cases:

- Large industrial company increasing the level of energy self-sufficiency and economic efficiency
- A fully electrified construction machine and the future energy scenario on the construction site

Based on these cases we present both the results achieved and the limitations of the model. Simulations revealed that no single measure could deliver the desired results. Significant benefits only emerged from an integrated, sector-coupled solution. Particularly effective is the combination of PV, battery storage, and heat pump – which dramatically increased self-consumption of solar power while reducing dependence on fossil fuels.
ROI analysis confirmed the economic advantage: while individual projects showed payback periods of 10–12 years, the combined scenario achieved significantly lower payback periods.
Our key insights: Success does not come from isolated measures but from the interaction of sectors. Only through simulation and integrated planning did the company discover the most profitable and sustainable solution.

REFERENCES

European Commission (2023), The European Green Deal, Striving to be the first climate-neutral continent.
European Commission (2023): Fit-for-55 Package and EU Climate Law
European Comission (2025), Clean Industrial Deal
APG (2024): Energy System Vision – CEOs4Future.
International Energy Agency (IEA) (2024): World Energy Outlook.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

1.02 Building the Future: Smart Energy Infrastructure for the Energy Transition
1.04 Coupling of Energy Sectors

PILGRIMS' BARN: A CARBON POSITIVE CLASS Q RETROFIT FOR POST-HYDROCARBON LIVING

SUMMARY

Pilgrims' Barn is an exemplar Class Q adaptive reuse project in rural England. This demonstrates how retrofit can surpass new-build performance standards. Achieving EPC A (134) and outstanding Whole Life Carbon Assessment (WLCA) results; it integrates passive solar design, high thermal mass, and triple-glazed fenestration to provide year-round comfort with negligible heating and cooling demand. Circular, nature-based systems include rainwater harvesting, integrated SuDS, reedbed wastewater, tertiary treatment; biodiverse landscaping, reduces environmental impact, while enhancing health and wellbeing. Fully electric, it is powered by 75 PV panels with 40.5 KWHs battery storage. WLCA results outperform LETI, RIBA 2030, and NZCBS benchmarks, demonstrating carbon negative performance; giving net carbon positive overall, over its 300-year design life. This paper evidences that rural Class Q conversions can deliver post-hydrocarbon living, with carbon negative, low-cost, and healthy outcomes.

MASTER PLANNING

This is critically important in large-scale development. This follows the principles of the King's Foundation. Even for Pilgrims' 1.2hectare site, it was still highly relevant; the footprint was fixed, but service locations and landscaping were of key importance, as was southern orientation for rooftop solar panels, passive heating and light for the house.

BUILDING CONSTRUCTION

The construction form followed the research work of Prof Brenda Vale; it included refinements from the directors of The Hockerton Housing Project in Nottingham. It follows 'Three Principles'. The first, Orientation, Second is Dense Building-mass of all internal walls, set on 300mm of concrete floor. Thirdly, this dense mass is enveloped in 300mm insulation, under the concrete floor, then wrapped up the outside of the internal leaf of the external walls. At the wall-top, it is integrated with 440mm roof insulation. High performing triple-glazing is essential. This construction retains heat in winter and protects it from over-heating in summer. From a median heat of about 22C, the house seldom moves more than 2C above or below this temperature.

CIRCULAR, NATURE BASED SERVICES

The rainwater harvesting tank provides some 80% of all water needs in the house and garden. This tank is also number 1 SuDS tank, to protect Pilgrims from flash-flooding. The overflow from this tank is the Wildlife pond, running through a water-holding swale and into the Reedbed pond, which removes nitrates and potash from waste-water after processing in twin septic tanks. Surplus flows into the neighbouring pond.

Energy is all electric and generated from 75 roof-fixed PVs energising the house and 2 electric cars. 3 Powerwall batteries hold 40.5 KWHs. In 2024, net export to grid, after deducting import was 3MWHs.

All systems are designed with ultra-low energy requirements. Pilgrims hot water is heated on demand to 50C; the insulated tank is set in a cupboard, densely packed with insulation around it. This reduces heating energy by a further 43%.

LANDSCAPING TO PROVIDE NATURAL BEAUTY AND PEACE

The whole, integrated SuDS system has been created with beauty and biodiversity in mind. It also serves to create places for recreation, relaxation and natural meditation; this helps people to re-connect with their roots in the natural world.

HIGH AIR QUALITY

Pilgrim's is fitted with internal and external heat and humidity sensors; internal air quality is constantly monitored for CO2, VOCs and particulates. Overall, the stats show a predominance of 'Excellent'.

WHOLE LIFE CYCLE ASSESSMENT (WLCA)

A WLCA conducted in accordance with the RICS Global Standard and EN 15978, quantifies embodied and operational carbon across the building life cycle. Results are compared against a notional building baseline, the UK Net Zero Carbon Buildings Standard (NZCBS) and industry benchmarks including RIBA 2030 and LETI residential targets. Pilgrim's Barn surpasses the Low Energy Transformation Initiative (LETI) Good Design (<400 $kgCO_2e/m^2$ A1-A5), sitting comfortably in Band B. Pilgrims Barn surpasses the RIBA 2030 Built Target (<625 $kgCO_2e/m^2$ A1-5, B1-5, C1-C4) Band B. It also outperforms the NZCBS for a new single-family home (<400 $kgCO_2e/m^2$ A1-A5). The exceptional operational Energy Use Intensity (EUI) of 17.5 kWh/m^2 GIA/yr – surpasses UK current & 2050 targets – NZCBS, LETI, RIBA & the UKGBC for both Retrofit (98-58 kWh/m^2 GIA/yr) & New Build (45-35 kWh/m^2 GIA/yr). These benchmarks of course exclude the onsite Solar PV Generation, which when included gives an improved Operational EUI of -38.4 kWh/m^2 GIA/yr.

Life Cycle Stage	$kgCO_2e/m^2$	$TonnesCO_2$
Upfront Embodied (A1-A5) Excluding Solar	367	170
Total Embodied Excluding Solar (A1-A5, B1-B5, C1-C4)	508	234
Total WLC (A1-A5, B1-B7, C1-C4)	**226**	**104**
Total WLC (A1-A5, B1-B7, C1-C4) Including EV	491	226

Table 1-1: Carbon emissions for Pilgrims Barn.

Total WLC (A1-A5, B1-B7, C1-C4) Excluding EV		
Life (Years)	$kgCO_2e/m^2$	$TonnesCO_2$
60 – Reference Study Period (RSP)	**226**	**104**
300	**-60**	**-27**

Table 1-2: 60-year & 300-year life cycles.

When you project out the Whole Life Carbon emissions with a 300-year design life, Pilgrims' Barn becomes a WLC Positive building.

FINAL SUMMARY

This paper demonstrates the potential of rural Class Q conversions to deliver negative energy costs, proven health benefits, remarkable whole-life carbon (WLCA) performance aligned with net-zero trajectories. By evidencing outcomes with robust WLCA data, it positions adaptive retrofit as a viable and replicable pathway for a post-hydrocarbon, built environment.

REFERENCES

Vale B and R. (2000) The New Autonomous House. Thames and Hudson.

RICS (2023) Whole Life Carbon Assessment for the Built Environment Global Standard 2nd Edition. Royal Institute of Chartered Surveyors, London, UK

RIBA, RICS, UKGBC, CIBSE, BRE, Carbon Trust (2025) UK Net Zero Carbon Buildings Standard Pilot Version, Net Zero Carbon Buildings Standard Limited, London, UK

CONFERENCE TOPIC

2.04 Life Cycle Assessment

1.15 Sustainable Renovation and Energy Retrofits

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AUTOMATED AND TRANSFERABLE UBEM GENERATION USING OPEN DATA FOR AUSTRIAN MUNICIPALITIES

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SUMMARY

Urban Building Energy Modelling (UBEM) generation is often made difficult by incompatible, incomplete and proprietary datasets – typically requiring substantial manual processing, which for the most part cannot be generalized and repurposed for other municipalities. This study presents a fully automated UBEM framework for Austrian municipalities using exclusively open data. The framework implements a hierarchical approach where open-, crowd-sourced and statistical data are used in a rule-based mapping. The methodology ensures comprehensive coverage for local data gaps. The underlying database encompasses building periods and condition, energy supply systems, building sizes and usage classifications. The open-source mapping tool enables any CityEnergyAnalyst user to immediately commence dynamic energy simulation for Austrian municipalities without geo-referenced data preparation. Preliminary validation demonstrates promising accuracy at municipal scale, with the framework serving as foundation for diverse energy planning applications.

Keywords: Urban Building Energy Modelling (UBEM), crowd-sourced data, open data, building typology, CityEnergyAnalyst, municipal energy modelling, GIS, automated mapping, Austria-wide database

BACKGROUND AND RESEARCH APPROACH

Current UBEM approaches face significant barriers including extensive local databases, manual archetype assignment, high costs, and limited accessibility for smaller municipalities. While existing automated frameworks by (Heidenthaler *et al.*, 2023), (Schiefelbein *et al.*, 2019), and (Nageler *et al.*, 2017) have made progress, they still require considerable local input data or rely on representative building scaling rather than individual building modelling.

This research addresses the fundamental challenge of building stock characterization at national scale: *How can open data be systematically processed through automated mapping tools to create open-source UBEM frameworks applicable across all Austrian municipalities?* The focus lying not on energy calculations themselves, but on establishing robust building assignments that enable high-quality downstream applications without extensive manual data preparation.

The framework recognizes that municipal data will always be available from local stakeholders, while substantial gaps remain. Rather than requiring complete datasets, the methodology implements intelligent gap-filling creating a foundation that maximizes data utilization while ensuring comprehensive coverage.

METHODOLOGY

To map a municipality in CEA, geo-referenced 3D models of the buildings (LOD1) and corresponding information regarding the number of storeys, building usage mix, original construction period, building condition (existing, renovated) and type of energy supply are required. First d**ata acquisition** combines OSM building footprints with federal DLM height data to generate LOD1 building models of the right volume and orientation.

In a second step explicit OSM usage classifications are used where available otherwise statistical probability distributions based on building cubature and municipal census correlations determine missing usages and building periods. The condition of the building is ultimately determined by a probability factor, depending on its age and expected energy saving potential – capped by the total renovation rate per decade. The assigned energy supply respectively the predominant energy source is based on the statistical distribution per federal state, construction period and building condition. **Archetype assignment** combines construction periods, renovation status and energy supply, as well as building size and usage type (e.g. warehouse and industry) to match buildings with archetypes from Austrian database based on the currently simplified database established in (Schneider, Drexel and Frech, 2025).
The attributive fidelity is validated against building data of municipalities with existing geo-referenced properties (Way2Smart Korneuburg) and residential building register (AGWR) where available through the project Klimagemeinschaften. Statistical analysis of the occurrence of archetypes in different types of communities is evaluated.

RESULTS

Initial validation across selected municipalities with available reference data demonstrates promising accuracy at the neighbourhood scale. While individual building assignments needs further analysis between specific archetypes, municipal-level building stock distributions show strong correlation with census data and regional patterns.
The framework produces complete building characterizations for Austrian municipalities, achieving comprehensive geometry via OSM/DLM integration, statistically consistent construction-period distributions, and usage classifications aligned with municipal development patterns. Preliminary analyses show systematic over- and under-representation of certain archetypes, suggesting additional sub-categorization; these insights push towards iterative refinement while reinforcing that improved assignment accuracy enhances downstream application quality.
The open-source framework enables fast, transparent municipal energy modeling with modular integration into CEA and QGIS workflows. Its exchangeable GIS-layer architecture allows non-technical users to update inputs via simple CSV files, facilitating crowd-sourced data improvement and citizen science applications.

Conference Topic: 2.08. Spatial Energy Planning with Emphasis on Renewable Energies

REFERENCES

Ceruti, A. *et al.* (2024) 'From Building to District: Accelerating Urban Building Energy Modeling with an Open-Source Database for Germany', in. *BauSim Conference 2024*, IBPSA-Germany and Austria (BauSim Conference), pp. 168–175. Available at: https://doi.org/10.26868/29761662.2024.22.
Heidenthaler, D. *et al.* (2023) 'Automated energy performance certificate based urban building energy modelling approach for predicting heat load profiles of districts', *Energy*, 278, p. 128024. Available at: https://doi.org/10.1016/j.energy.2023.128024.
Nageler, P. *et al.* (2017) 'Novel validated method for GIS based automated dynamic urban building energy simulations', *Energy*, 139, pp. 142–154. Available at: https://doi.org/10.1016/j.energy.2017.07.151.
Schiefelbein, J. *et al.* (2019) 'Automated urban energy system modeling and thermal building simulation based on OpenStreetMap data sets', *Building and Environment*, 149, pp. 630–639. Available at: https://doi.org/10.1016/j.buildenv.2018.12.025.
Schneider, S., Drexel, R. and Frech, C. (2025) *Klimaneutrales Alliiertenviertel*. Wien. Available at: https://www.data.gv.at/katalog/dataset/a6bb0ae7-6059-47c1-8ab3-bdfb2dbddb77#resources (Accessed: 18 August 2025).

SOLAR HEATING FOR INDUSTRIAL PROCESSES (SHIP)

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SUMMARY

Solar Heating for Industrial Processes (SHIP) has emerged as a key focus area for Soltrain+ in the Southern African region. In Zimbabwe, training sessions held in 2024 and 2025 did not yield immediate practical outcomes. To strengthen capacity, Energy Audit Training was conducted—first online in December 2024, followed by an in-person session in February 2025, which included a technical tour of a potential demonstration site at CAFCA. These activities were aimed at preparing for formal energy audits and subsequent SHIP project designs. Initial assessments identified potential application opportunities in the agro-processing, beverage, and pharmaceutical industries. Preliminary findings from the copper electrolysis process at CAFCA, Zimbabwe, are also presented.

INTRODUCTION

Over the past 15 years, solar thermal applications in Zimbabwe have been predominantly residential. The national energy roadmap now highlights industrial applications as critical for achieving the target of 0.1 m² per capita solar thermal installation by 2030. Zimbabwe's strong agricultural, industrial, and mining sectors currently rely heavily on fossil fuels, particularly coal. As a signatory to the Nationally Determined Contributions (NDC), Zimbabwe seeks to reduce fossil fuel dependence and align with global climate commitments[12].

METHODOLOGY

The study employed a desktop review of SHIP potential across Zimbabwean industries. Analysis focused on companies previously engaged in SHIP training sessions, assessing their products, workforce size, estimated heating and cooling needs, factory floor area, and current energy sources.

RESULTS

Preliminary findings highlight a range of industries suitable for SHIP applications.

Table 1: Companies and their categories

Company	Process	Employee Sizes	Product
Delta	process water heating, wort boiling, pasteurisation, bottle-washer heat, steam for CIP	+5000	Brewing (beers, traditional beers), soft drinks and bottling.
Tanganda	processing (withering, rolling, drying)	200-300	Tea, Avocado and Macadamia
Ingwebu	process water heating, wort boiling, pasteurisation, bottle-washer heat, steam for CIP	200-500	Traditional beer and Mahewu (non-alcoholic drink)
United Refineries	oil extraction (solvent/expeller), drying, deodorising & refining require medium to high heat	500-1000	Cooking oils, fat processing, soaps & detergents

[12] https://pia.ndcpartnership.org/2021/country-stories/zimbabwe/

Olivine Industries	oil extraction (solvent/expeller), drying, deodorising & refining require medium to high heat	1200	Olivine cooking oil, margarine, laundry soap
National Foods	drying (grain, maize), baking ovens, steam for process cleaning and some heat for extrusion/pelleting of feeds.	5000	Mealie meal
Cairns	Poultry and meat processing	200-500	Cornflakes, Peanut Butter
Schweppes	Beverage processing	200-500	Beverage
Cafca	Copper Electrolysis	300-500	Copper cabling

COPPER ELECTROLYSIS PROCESS

The Copper Electrolysis process is summarised in the SCADA disgram shown in Figure 1.

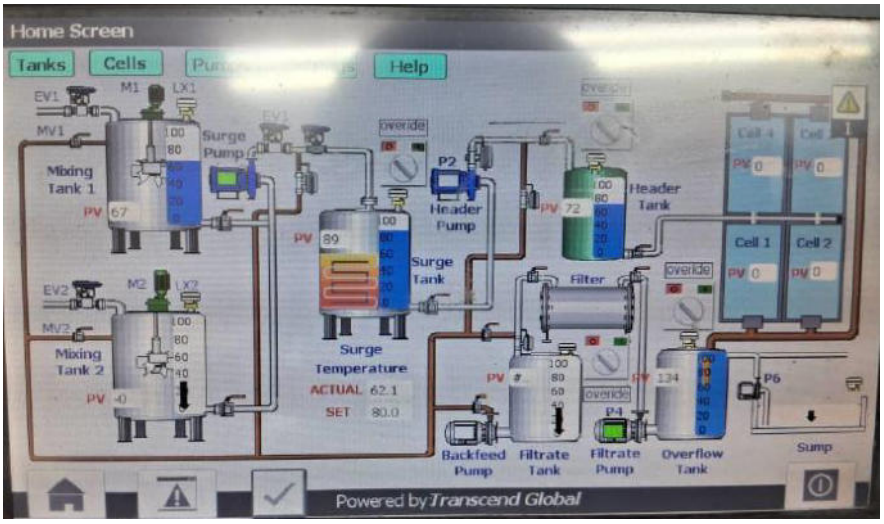


Fig. 1: SCADA diagram of the Copper Electrolysis process (courtesy CAFCA)

The copper electrolysis process at CAFCA was examined as a potential SHIP demonstration project. A SCADA diagram (Fig 1) illustrates the process flow and associated heating requirements.

CONCLUSION

This study demonstrates the potential for SHIP adoption in Zimbabwean industries, particularly within agro-processing, beverages, and mining. The copper electrolysis process at CAFCA was identified as a promising demonstration case. Future work will focus on the implementation phase, with results to be shared once pilot projects are operational.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

TiO_2 PHOTOANODES FOR PHOTOELECTROCHEMICAL WATER SPLITTING

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SUMMARY

Photoelectrochemical water splitting is a promising technology for sustainable hydrogen production solely from sunlight. In this work, highly stable TiO_2 photoanodes with various dopants were developed, achieving improved activity compared to bare TiO_2 photoelectrodes. A preliminary screening is performed to select suitable photoanodes for integration in a 25 cm² PEC cell. The successful operation of the PEC cell was demonstrated in an advanced test set-up providing a stable and optimized testing environment, such as a precise temperature control.

INTRODUCTION

Photoelectrochemical (PEC) water splitting is gaining interest, as alternative way for renewable hydrogen production, using sunlight as an energy source. Advantages are the use of low cost, abundant materials, and having a lower ecological footprint than competitive technologies such as photovoltaic coupled electrolysis. However, a low TRL and high costs demand significant effort for making the system competitive. Major challenges are the development of stable and active photoelectrodes, scale-up of lab-based systems, and optimizing operation conditions, aiming for an application (Schneidewind, 2022; Song et al., 2022; Vilanova et al., 2024). TiO_2 photoanodes are intensively characterized and show high stability, but they are only active under UV light and thus lead to a low solar-to-hydrogen efficiency. Therefore, addition of dopants is used to shift the absorbance into the visible light range (Sawal et al., 2023). Beside choosing well performing photoelectrodes, establishing a defined and appropriate test set-up is essential for efficient water splitting. So far, most PEC water splitting systems are lab systems for photoelectrode screening in small scale and under ambient conditions, although, operation at elevated temperature and pressure and concentration of sunlight is appreciated to enhance current densities and solar-to-hydrogen efficiencies (Liang et al., 2024; Qureshi and Tahir, 2024; Shi et al., 2015). A scale-up of the photoelectrode is necessary to increase the TRL and enable application of the system. In this work, the developed TiO_2-based photoanodes are integrated in an advanced PEC reactor that is suitable for scale-up to 400 cm² active area and characterized in a highly sophisticated testing facility.

METHODOLOGY AND RESULTS

Photoelectrode development: TiO_2 powder suspension with various additives are prepared and plasma spray coating is used for photoanode preparation. Variation of spraying temperature, suspension composition and coating passes define the layer thickness, structure and stability and thus having a significant influence on the overall systems performance.

Photoelectrode screening: A prior characterization of the developed photoelectrodes is done in a 3-electrode set-up with an active area of 4 cm². Screening activities are performed under illumination of one sun and compared to reference measurements in the dark. A bias up to 1.8 V was applied to enable efficient water splitting reaction

and hydrogen production. It was proven that the coating process has a significant influence on the layer stability and achievable photocurrent density. Compared to bare TiO_2, that shows very little activity upon illumination, a significant photocurrent and a reduced onset potential are measured when using TiO_2 photoanodes with dopants such as TiN, TiC, Fe_2O_3 or ZnO.

PEC cell design and electrode scale-up: The best performing photoanodes were scaled-up in a first step from 4 to 25 cm² active area and operated in the developed PEC flow cell. The cell design was supported by CFD simulation for optimization of flow behaviours, pressure losses, and product evolution.

PEC testing facility and electrochemical characterization: A novel PEC testing facility was developed for electrochemical characterization of the larger scale photoelectrodes, evaluation of the cell design and long-term stability measurements. The testing facility includes all features that are necessary for advanced characterization under optimized conditions aiming an application of PEC water splitting. Precise temperature measurement and regulation allow stable operating conditions; the system is suitable for hydrogen production up to 6 bar and a solar simulator allows constant illumination at 1 sun as well as simulating variable intensity over the day and year. First results show a stable photocurrent production under careful control of the flow rate and operating temperature compared to lab-scale systems without controlled operating conditions.

CONCLUSIONS AND OUTLOOK

Doping of the TiO_2 photoanodes led to increased photocurrent density due to absorption in the visible light range. A first scale-up of photoelectrodes from 4 to 25 cm² was successfully accomplished and photoelectrode were integrated in the developed PEC cell. Commissioning of an advanced PEC testing facility is finished and first measurements proved the importance of defined and controlled operating conditions, especially stable operating temperatures, for stable operation of the PEC cell.

The next steps are the investigation of optimal operating conditions – variable temperature, increased pressure, and the changing of illumination conditions. Moreover, proving long-term stability and achieving scale-up to 400 cm² are the major objectives to push the technology towards application.

REFERENCES

Liang, F., van de Krol, R. and Abdi, F. F. (2024) 'Assessing elevated pressure impact on photoelectrochemical water splitting via multiphysics modeling', *Nature communications*, vol. 15, no. 1, p. 4944.

Qureshi, F. and Tahir, M. (2024) 'Photoelectrochemical water splitting with engineering aspects for hydrogen production: Recent advances, strategies and challenges', *International Journal of Hydrogen Energy*, vol. 69, pp. 760–776.

Sawal, M. H., Jalil, A. A., Khusnun, N. F., Hassan, N. S. and Bahari, M. B. (2023) 'A review of recent modification strategies of TiO2-based photoanodes for efficient photoelectrochemical water splitting performance', *Electrochimica Acta*, vol. 467, p. 143142.

Schneidewind, J. (2022) 'How Much Technological Progress is Needed to Make Solar Hydrogen Cost-Competitive?', *Advanced Energy Materials*, vol. 12, no. 18.

Shi, X., Cai, L., Ma, M., Zheng, X. and Park, J. H. (2015) 'General Characterization Methods for Photoelectrochemical Cells for Solar Water Splitting', *ChemSusChem*, vol. 8, no. 19, pp. 3192–3203.

Song, H., Luo, S., Huang, H., Deng, B. and Ye, J. (2022) 'Solar-Driven Hydrogen Production: Recent Advances, Challenges, and Future Perspectives', *ACS Energy Letters*, vol. 7, no. 3, pp. 1043–1065.

Vilanova, A., Dias, P., Lopes, T. and Mendes, A. (2024) 'The route for commercial photoelectrochemical water splitting: a review of large-area devices and key upscaling challenges', *Chemical Society reviews*, vol. 53, no. 5, pp. 2388–2434.

CONFERENCE TOPIC

1.14. Solar-to-X Technologies for Fuels and Chemicals

SIMULATION AND EVALUATION OF AN INTER-MUNICIPAL DISTRICT HEATING NETWORK

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SUMMARY

This work presents the development and evaluation of an inter-municipal district heating network (IMDHN) of five existing district heating (DH) networks in the Reallabor WEIZplus region (Austria), carried out within the project FossilFree4Industry. The main motivation is to make DH accessible for industrial consumers and to enable a doubling of the supplied heat volume to appr. 200 GWh / a, while supporting broader objectives of decarbonisation, renewable integration and reliable heat supply. The methodology combines a status-quo analysis of the existing DH networks, a GIS-based identification of Areas of Interest (AOIs) for expansion and densification, and energy modelling and simulation studies with energyPRO. Different future scenarios in terms of demand, supply and timeline were defined and analyzed. Results show that an interconnected DH network improves load balancing, increases renewable utilization and reduces fossil-based peaks, rendering the IMDHN idea to represent a feasible and effective strategy to achieve a resilient and climate-neutral regional heat supply.

INTRODUCTION

Decarbonising the heat sector is a key challenge to achieve European and Austrian climate targets. Particularly in industrial regions, the transformation of heat supply requires innovative approaches that combine renewable energy integration, sector coupling, and efficient infrastructure use.

The region Weiz–Gleisdorf in Styria (Austria) is part of the living lab Reallabor WEIZplus, where the project *"FossilFree4Industry"* aims to develop and demonstrate different model solutions for fossil-free energy systems, interconnection of district heating networks, the integration of industrial consumers, and the utilization of regional renewable resources. This region is characterized by a high density of industrial companies, existing but unconnected district heating systems, and diverse renewable potentials.

One of the investigated demonstrators is the implementation of an inter-municipal district heating network (IMDHN), merging currently five stand-alone district heating systems while modernizing and decarbonizing the existing networks and providing sustainable heat supply options for residential and industrial customers.

Fig 46 illustrates the concept of the IMDHN and key performing indicators (KPI´s): the existing DH networks of Weiz, Unterfladnitz, St. Ruprecht, Wollsdorf and Gleisdorf are hydraulically interconnected to form a continuous backbone, enabling load balancing, efficient utilisation of renewable resources, and improved supply security.

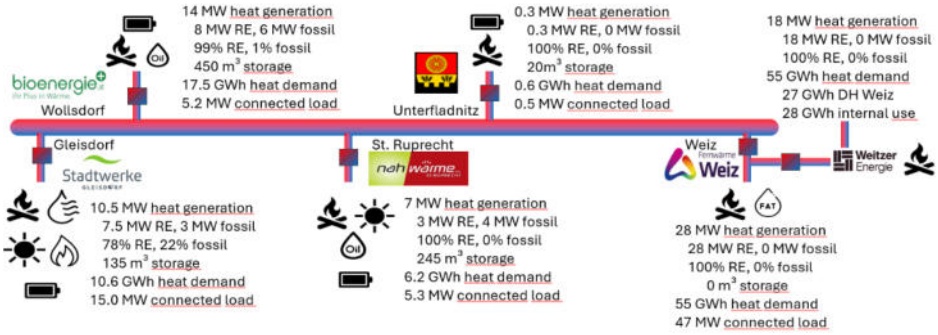


Fig 46: Overview of the district heating networks in the Weiz–Gleisdorf region and main KPI´s (status 2023)

METHOLDOLOGY

The analysis combines a multi-step approach:

• Status-quo analysis of five existing district heating systems (heat demand, customer structures, generation units, see Fig 46).

• GIS-based analysis to identify Areas of Interest (AOIs) for future expansion/densification potential.

• Development of future heat demand scenarios up to 2040, with an approximately 200 GWh heat demand.

• Simulation-based analysis and evaluation of individual networks (no IMDHN) and interconnected systems (IMDHN) using energyPRO.

RESULTS

The simulations of the different future scenarios demonstrate clear strengths of an IMDHN and enables:

• Load balancing between municipalities and reduction of peak loads.

• Higher renewable generation shares mainly from biomass, heat pumps, solar thermal and biogas.

• A significant reduction of fossil-based backup generation.

Overall, the IMDHN leads to a reduced use of fossil fuels, which directly lowers CO_2 emissions and improves the overall energy efficiency of the system. With interconnection and all producers available (AE 2040), the heat demand can be fully supplied with a renewable share of 94%, compared to 88% in the isolated case. Without interconnection, fossil-fired units need to operate more frequently despite sufficient technical capacity in the system. In renewable-only scenarios (EE 2040), however, a substantial supply gap (20-30 GWh / a) remains even with IMDHN, highlighting the need for additional renewable capacities to reach full coverage. Fig 47 and Fig 48 the IMDHN enables higher utilisation of biomass and CHP, reduces fossil peaks, and increases renewable coverage, while renewable-only operation reveals the additional expansion needs for a future fossil-free supply.

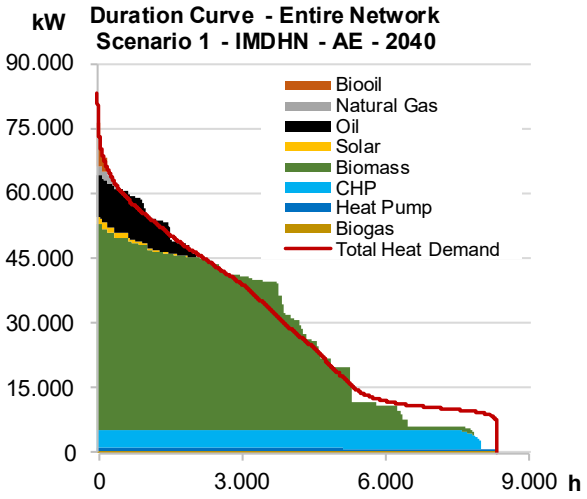


Fig 47: Duration curve - Scenario 1 with IMDHN - AE

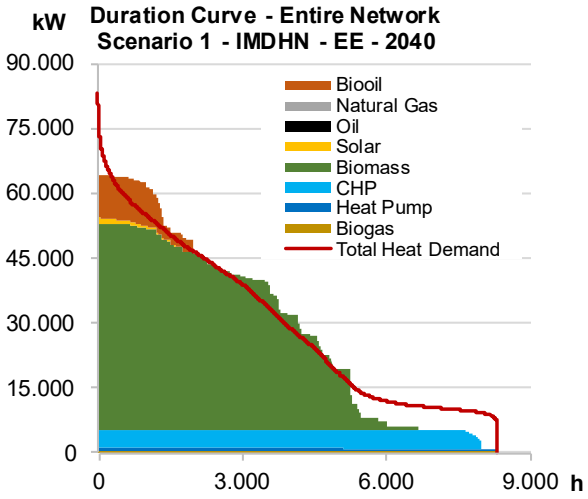


Fig 48: Duration curve - Scenario 1 with IMDHN - EE

CONCLUSION

The simulation and evaluation study demonstrates that establishing an inter-municipal district heating network is both technically feasible and strategically effective for achieving long-term climate neutrality. By interconnecting existing infrastructures, extending the network, and enforcing the use of renewable energy sources, the supplied heat can be doubled to around 200 GWh/a by 2040, with a renewable share of 94%. Full decarbonisation, however, will require further expansion of renewable generation capacities.

CONFERENCE TOPIC

Future District Heating and Cooling Solutions / Digitalization for Smart, Resilient Energy Systems

INTEGRATION OF INDUSTRIAL HEAT PUMPS

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SUMMARY

Heat pumps are key in the energy transition, reducing energy consumption and CO_2 emissions when powered by low-carbon electricity. They recover waste heat or use renewable sources (air, geothermal) to generate high-temperature heat. Their industrial adoption is still limited but shows strong potential given favourable conditions. Opportunities include continuous heat demand, high-temp technologies, on-site heating/cooling needs, and supportive regulations (EU-ETS, White Certificates). Yet some barriers remain: technical maturity, space limits, temperature constraints, electricity availability, and lack of awareness. Projects' profitability depends on electricity vs fossil fuel prices, load rate (NHEPP), and outlet temperature. Our study outline three promising configurations: recovery from cooling systems, use of dryer vapour/geothermal, or ambient air for large-scale low-temp needs. In all cases, environmental gains are major: up to 97% CO_2 reduction, with ETS-related financial benefits. We aim to present in detail the DALKIA TRANSPAC project which demonstrates a successful integration of an innovative high-temperature heat pump, proving its economic, environmental, and operational viability. The HP delivers hot air at 140°C, with a lift of +50°C (electrical power 240 kW).

FORMATTING

Heat pumps are set to play a key role in the energy transition of industry, reducing both energy consumption and CO2 emissions, as long as local electricity is low carbon. These devices use a thermodynamic cycle that allows calories to be recovered from various heat sources to produce heat at higher temperatures by supplying electricity. They can use renewable sources, such as ambient air or geothermal energy, as well as waste heat, which is regularly generated in industrial plants. However, the use of heat pumps in the industrial sector is still in its infancy and it is therefore useful to identify the potential success factors.

Several technical opportunities are accelerating the uptake of heat pumps: the continuous consumption of process heat, the emergence of technologies capable of meeting higher temperature requirements, simultaneous heating and cooling requirements on site, the presence of an easily exploitable heat source or the existence of a centralised hot water or steam network. Added to these factors are economic and regulatory opportunities, such as low electricity prices, the inclusion of certain heat sources in the EU Emissions Trading Scheme (EU-ETS) or the eligibility of certain heat sources for the French White Certificates (Certificats d'Economie d'Energie). For many industrial companies, the combination of several of these factors leads to a favourable economic balance and makes heat pump projects particularly relevant (cf. Figure 1).

Nevertheless, obstacles of various kinds (technical, operational, economic or regulatory) persist and limit the use of heat pumps: mismatch between heat consumption and heat sources, limited space available, maximum temperature achievable by current equipment not adapted to needs, insufficient technological maturity of high-temperature heat pumps, lack of electrical availability or even unfavourable economic balance in certain cases. These limitations are compounded by the lack of awareness of the various players in the value chain, which reduces the ability of manufacturers to evaluate and use these solutions effectively, and can also perpetuate

certain barriers and psychological prejudices regarding the reliability, performance and durability of this type of equipment.

Analyses and feedback show that the main factors affecting the level of profitability of a heat pump installation are the difference between the price of electricity and fossil fuels (gas, oil), the NHEPP (or load rate) and the outlet temperature. It is therefore necessary to correctly characterise the heat demand on the consumer side and identify possible optimisations (temperature reduction, demand smoothing, etc.) in order to optimise the size of the system and maximise its performance, as heat pump systems remain CAPEX intensive.

In addition, several configurations have emerged as particularly relevant for the installation of heat pump systems:

- Where waste heat is easy to recover, for example from chillers or cooling towers. The economic performance remains attractive even at low load rates.
- Where specific heat sources, such as dryer vapour or geothermal energy, are used for high-capacity projects. This remains relevant even if the number of full load equivalent hours (NHEPP) is limited to 3,000 hours per year.
- For heat at low temperatures (around 60°C), with a capacity of more than 500 kWth and integration without major complexity, the use of ambient air is suitable. This configuration concerns a significant proportion of industrialists and could be massively replicated.

From an environmental point of view, heat pumps allow a significant reduction in CO2 emissions compared to gas solutions (at least in France). Under favourable conditions, this reduction can reach 97% and is almost always higher than 90%. For sites covered by the EU ETS (Emissions Trading Scheme), this environmental gain translates into additional savings linked to a reduction in the purchase of allowances on the market or the possibility of reselling unused free allowances.

Every industrial has the possibility to pre-estimate the relevance of a heat pump installation project by qualifying the exploitable heat sources, their heat demand and the constraints of their site (capacity of the electrical network, available space, etc.). On the other hand, the elaboration of an installation scenario requires the involvement of a specialised design office. The aim of this study is to provide project managers with the keys to understanding, a preliminary approach and a tool for investigating the possibilities for assessing the potential of these technologies on their site.

In addition to the possibilities offered by current equipment, the development of new technologies aimed at achieving higher temperatures could increase the field of application of heat pumps in industry.

The DALKIA TRANSPAC project illustrates the successful integration of an innovative high-temperature heat pump in environmental, economic and operational terms. It is an important stage in the maturation of HT heat pumps, opening the door to new applications, and should be replicated by other manufacturers operating in similar contexts.

In fine, heat pumps are technological solutions that make it possible to exploit the potential of waste heat (common in industry) or decarbonised energy sources. They therefore have advantages that allow them to establish themselves in certain industrial sectors as important solutions for decarbonisation and energy resilience. As technology improves, more and more applications will be covered by heat pumps.

If a project is sized correctly, it will deliver economic and environmental benefits without placing prohibitive operational constraints on teams.

FIGURES

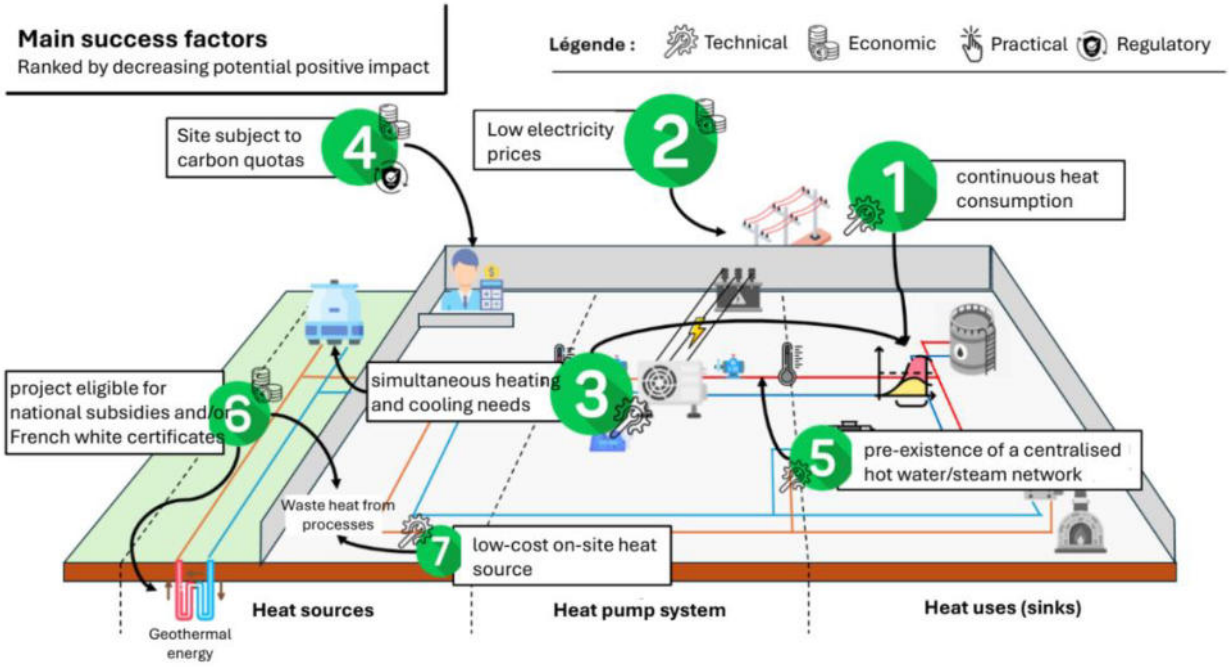


Figure 1. Factors favouring the deployment of heat pump systems in industry

REFERENCES

[1] INSEE, 'Energy consumption in industry − Companies in France', insee.fr. Accessed: 23 August 2024. [Online]. Available at: https://www.insee.fr/fr/statistiques/5758772?sommaire=5759063
[2] 'National Low Carbon Strategy', Ministry for Ecological and Solidarity Transition, March 2020. Accessed: 23 August 2024. [Online]. Available at: https://www.ecologie.gouv.fr/sites/default/files/documents/2020-03-25_MTES_SNBC2.pdf
[3] 'Strengthening Industrial Heat Pump Innovation - Decarbonising Industrial Heat', July 2020. [Online]. Available at: https://www.sintef.no/globalassets/sintef-energi/industrial-heat-pump-whitepaper/2020-07-10-whitepaper-ihp-a4.pdf
[4] 'National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism,' European Environment Agency (EEA), April 2024.
[5] 'Complete energy balances,' Statistical Office of the European Union (Eurostat).
[6] Illustrative diagram of the Emissions Trading System (ETS). [Online]. Available at: https://www.senat.fr/rap/r21-576/r21-5762.html
[7] 'La Chaleur Fatale' (Fatal Heat), ADEME, 2017 edition. [Online]. Available at: https://www.EnRchoix.idf.ademe.fr/ressources/chaleur-fatale/chaleur-fatale-8821.pdf
[8] '2023 electricity balance sheet - Emissions | RTE'. Accessed on: 23 August 2024. [Online]. Available at: https://analysesetdonnees.rte-france.com/bilan-electrique-2023/emissions#Introduction
[9] 'DECRYPTION SHEET - CSRD and sustainability reporting',

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

- 1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

STUDY ON THERMAL PERFORMANCE AND APPLICATION POTENTIAL OF PHASE CHANGE VACUUM CERAMIC THERMAL INSULATION MATERIALS IN BUILDING RENOVATION IN HOT SUMMER AND WARM WINTER ZONES

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SUMMARY

The Hot Summer and Warm Winter (HSWW) climate zone has high temps and humidity, increasing cooling energy use as AC is needed for comfort. Conventional insulation (e.g., rock wool, polyurethane, XPS)—with 0.03–0.08 W/(m·K) conductivity and 20–100mm thickness to meet standards—raises costs, installation issues, and delamination risks. In contrast, PCMs use high latent heat to absorb/release heat during phase changes, stabilizing envelope temps via daily swings, improving indoor stability, and offering lightweight, high-performance retrofit solutions.

This study examines a phase-change vacuum ceramic insulation material combining inorganic eutectic PCMs with vacuum ceramic microspheres, evaluating its performance in HSWW zone opaque envelope renovations via field tests and EnergyPlus simulations. Key goals:

1.Validate manufacturer's ultra-low conductivity (0.003 W/(m·K), steady-state) in real dynamic conditions;2.Show 1mm ultra-thin coating outperforms traditional materials;3.Explore benefits: lighter/thinner layers, better thermal stability, simpler construction;4.Propose climate-specific strategies using DSC-derived phase-change temps.

Results confirm its strong insulation and temp regulation, proving effective for HSWW energy-efficient retrofits.

INTRODUCTION

A phase-change vacuum ceramic thermal insulation coating, cored with composite eutectic PCM, integrates phase change energy storage, vacuum insulation, infrared reflection, and nano-thermal insulation (Table 1). Unlike traditional materials (e.g., XPS requiring 40mm thickness), it uses a 1mm ultra-thin layer to match or exceed thermal performance (steady-state thermal conductivity: 0.003 W/(m·K), per manufacturer tests). This reduces construction difficulty, cost, and risks (e.g., peeling) while offering alkali resistance, weather resistance, environmental friendliness, and non-toxicity. Suitable for exterior walls, roofs, etc., it meets the "thin-layer, high-efficiency, safe, and durable" requirements for green renovation of high-energy-consuming buildings in HSWW regions.

Table 1:Key technical indices of phase change vacuum ceramic insulation material.

Item	Technical Index	Standard
Thermal Conductivity	0.003	GB/T 13475-2008
Thermal Resistance	0.333	JGJ/T 132 JGJ/T357
Thermal Storage Coeff.	6.000	GB/T 50176-2016
Specific Heat Capacity	1450 J/(kg·K)	GB/T 19466.4-2016
Dry Density	1230 kg/m³	GB/T 6750-2007
Fire Rating	A2	GB 8624-2012

Table 2:Performance comparison of insulation materials

Type	Production Method	Thermal Conductivity (W/m·K)	Chemical Stability	Remarks
Rock Wool	High-temp melting	0.035–0.050	Very stable	Prone to water absorption
Foam Glass	High-temp foaming	0.047–0.052	Very stable	Easy processing
Polyurethane	Mold foaming	≥0.032	Stable	Moderate strength

METHODOLOGY

Materials:
Phase change vacuum ceramic insulation (target thickness: 1 mm), large tiles (300 mm × 300 mm × 50 mm), wooden boxes (open top), XPS board (40 mm thick; λ = 0.03 W/(m·K)), and aluminum foil tape.
Pretreatment:
① Line the inner surfaces of wooden boxes (excluding the top opening) with XPS boards, sealed externally with foil tape to ensure unidirectional heat flow .
② Coat one tile (Group A) with the material (dry film: 1 mm;); leave another (Group B) uncoated. Cure both for 24 h.
③ Place samples on box openings with coated/inner surfaces facing downward.
Testing:
Attach 4 thermocouples each to the top (air-exposed) and bottom (box-contacting) surfaces of both samples (8 total; Fig. 4). Record data at 10 s intervals.
② Conduct a 24 h test (9:00–9:00) under natural sunlight on a balcony.
③ Analyze temperature differences (ΔT = surface – internal temperature), focusing on peak (noon), trough (night), and average ΔT. Correlate with PCM's phase change temperature range (pre-tested via DSC).
④ Validate using EnergyPlus: Simulate thermal response with Guangzhou weather data and manufacturer parameters (λ = 0.003 W/(m·K)), comparing results with experimental data.

RESULTS

Experiments and simulations confirm the material's superiority in three aspects:
Exceptional Insulation & Dynamic Regulation:
In 24 h tests (Fig. 5), Group A (coated) showed smaller temperature fluctuations than Group B: peak temperature reduced by 3°C (max: 50°C at 14:00), and slower cooling at night (min: 30°C at 6:00). The synergy of "high thermal resistance + PCM buffering" stabilizes indoor temperatures, reducing AC dependency.

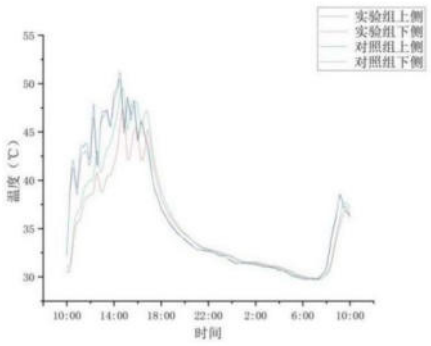


Fig.5 Experimental Results

Ultra-Thin Profile & Space Efficiency:

The ultra-low λ (0.003 W/(m·K)) and thin application (2 mm) maximize usable area. For a 3×3 m room, it adds 0.543 m² (+6.5%) vs. 45 mm traditional mortar and 0.194 m² (+2.2%) vs. 15 mm aerogel. In a typical 3-bedroom unit, usable area increases from 95 m² (mortar) or 97.1 m² (aerogel) to 98.3 m² (Fig. 6).

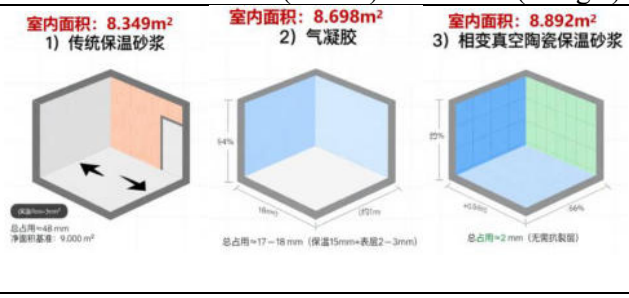


Fig.6 Comparison of indoor available areas with different insulation materials

Simplified Construction & Adaptability:

Spray/roll application covers complex surfaces, reducing scaffolding and rework. The system eliminates 3–5 layers (e.g., anti-crack mortar, mesh, anchors) vs. traditional methods (Fig. 7), preventing voids/delamination. Suitable for retrofits, equipment insulation, and thermal bridge remediation.

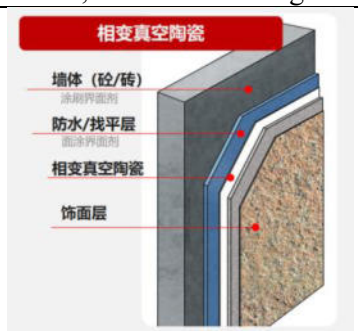


Fig. 7 Phase change vacuum ceramic insulation structure

Cost-Effectiveness:

Though traditional materials (e.g., rock wool) have lower unit costs, the total system cost for phase change ceramic is just 65 RMB/m²—far below VIP (340 RMB/m²) or nano-silica board (140 RMB/m²)—when factoring in labor, time, and space savings (valued at 10k RMB/m²;).

Although the material has excellent basic properties, DSC tests (Figure 8) reveal a key limitation: its phase transition range (-27.8℃ to -10.2℃, peak -13.9℃) mismatches HSWW regions' building thermal needs. With long, hot summers and mild winters, its current phase change temperature is too low to regulate summer heat, limiting its use.

To address this, microencapsulating PCMs (encasing core materials in micro-nano carriers) is a key optimization path: 1) precisely adjust phase change temperatures to match HSWW's summer heat absorption/winter heat release; 2) enhance stability (prevent leakage, improve durability) while retaining ultra-low conductivity, thinness, and easy construction, boosting applicability in complex scenarios.

In short, the material excels in insulation, space, construction, and cost. With optimized phase change temperatures via microencapsulation, it could become a key solution for upgrading HSWW building envelopes.

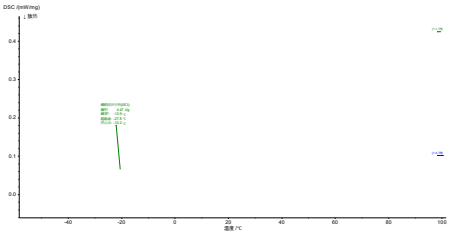


Fig. 8 DSC test results

CONFERENCE TOPIC

ROADMAP FOR ZONE-SPECIFIC RENEWABLE HEAT SUPPLY IN OTTENSHEIM

Johannes Rammerstorfer, Katharina Franziska Schlager, Klemens Leutgöb, Rachel Leutgöb

e7 energy innovation & engineering

ABSTRACT

SUMMARY

The project ModularHeatNet develops a roadmap for the decarbonization of the suburban municipality Ottensheim (Austria), where currently around 80% of the heat demand is supplied by fossil fuels (natural gas network). The project combines advanced spatial energy analysis with strong local stakeholder involvement to identify technically, economically and socially viable pathways. A modular, zone-specific approach to heat network planning is applied, integrating renewable energy sources with a strong focus on the efficient and fair use of local groundwater resources. By combining scientific modelling and participatory processes, ModularHeatNet provides a transferable framework for climate-neutral, resource-efficient and citizen-oriented heat supply in suburban contexts.

Keywords: modular heat networks, groundwater utilization, energy planning, participatory approach, suburban decarbonization, 5th generation district heating and cooling, 5GDHC.

INTRODUCTION

Suburban municipalities face particular challenges in transitioning to a carbon-neutral heating supply. Standard solutions, such as large-scale biomass heating plants or purely individual heat pump installations, often fail to meet the technical and socio-economic requirements of suburban settlement patterns. In Ottensheim, Upper Austria, with approx. 5,000 inhabitants, around 80% of heating is still fossil-based. The municipality is confronted with the urgent question whether a future centralised solution will be available or whether households must individually invest in long-term alternatives. Without guidance, citizens risk uncoordinated decisions that may undermine collective, more efficient solutions.

Against this background, ModularHeatNet addresses the need for a scientifically sound yet practically feasible roadmap that aligns technical innovation with local governance and citizen acceptance.

OBJECTIVES AND METHODOLOGY

The project's core objective is to design a modular, zone-specific heating system that flexibly adapts to varying settlement densities and building types, including solutions as 4th generation district heating and 5th generation district heating and cooling networks. Instead of a one-size-fits-all solution, Ottensheim is subdivided into energy zones where different network typologies (low-temperature grids, anergy networks, groundwater-based sub-grids) are assessed. This approach ensures that each part of the settlement is supplied with the most efficient and resilient solution, while still allowing for future integration into a coherent overall system.

A central innovation lies in the coordinated use of local groundwater resources. Individually drilled wells for decentralized heat pumps often lead to inefficient under-utilization of the resource and legal restrictions once water rights are exhausted. By integrating groundwater as a shared heat source within modular sub-networks, *ModularHeatNet* maximises efficiency, ensures fair access for many users, and safeguards the long-term sustainability of the aquifer.

The technical methodology combines:

- GIS-based energy spatial modelling (QGIS) on building level,
- hourly demand and network simulations using City Energy Analyst (CEA) and nPro,

- scenario development until 2050 including climate change adaptation and future building stock evolution,
- multi-criteria evaluation (technical, economic, ecological, organisational).

Parallel to the simulations, a series of stakeholder workshops with the municipality, citizens, and potential energy service providers ensure that technical scenarios are aligned with social acceptance, financing options, and governance models.

EXPECTED RESULTS AND DISCUSSION

The main outcome is a solid decision-making basis for the municipality, integrating technical feasibility, cost-benefit assessment, ecological impact, and organisational models. A stepwise implementation roadmap provides planning security for both the local authority and private households. By transparently comparing options and involving citizens early, acceptance for joint solutions is significantly enhanced.

Key expected benefits include:

- Demonstration of how modular zoning enables flexible and scalable network expansion, avoiding lock-in to single technologies.
- Provision of fitting business models.
- Enabling synergies with civil engineering projects (e.g. roadworks, flood protection, drinking water supply revitalization), thereby reducing overall costs.
- Significant contribution to climate neutrality by providing a roadmap for step-by-step implementation agreed with the municipality.
- Enhanced climate resilience by integrating cooling supply into selected network typologies.

Beyond Ottensheim, the modular, transferable planning approach addresses a broader need of suburban municipalities across Europe that struggle with the limitations of conventional solutions.

CONFERENCE TOPIC

2.08. Spatial Energy Planning with Emphasis on Renewable Energies

1.02. Building the Future: Smart Energy Infrastructure for the Energy Transition

1.08. Future District Heating and Cooling Solutions

LOW TECH, LOW EMISSIONS:-
CAN LOW TECH ADAPTATION TECHNIQUES OFFER THE MOST EFFECTIVE SOLUTIONS FOR REDUCING CARBON EMISSIONS IN THE UK'S EXISTING BUILDINGS?

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SUMMARY

'Number 23' is a decade long residential retrofit project, recently completed. This paper is the first instalment of evidence-based, in-use building performance data emerging from the low-tech retrofit strategy, one that utilises selected tenets of passive solar design techniques allied with renewable energy and BESS (Battery Energy Storage System) Initial results include; 60point improvement in SAP Rating, 85% reduction in fabric heat loss, 'Good' Indoor Air Quality (WHO. 2007) Naturally ventilated and 100% reduction in fossil fuels for heating. A comprehensive Life Cycle Analysis concludes 'Number 23' metrics surpass LETI, RIBA, RICS & NZCBS Best Practice standards.

INTRODUCTION

'Number 23' is the retrofit of a 1960's, 3-bedroom home, now operating free of fossil fuels, is naturally ventilated, largely naturally heated, achieving the UK's highest levels of energy efficiency.
Third party verification and certification for energy efficiency and carbon emissions has been undertaken using the Standard Assessment Procedure (SAP) Calculated, is an unprecedented 60point increase in the SAP Rating using the Full SAP methodology, not Rd (Reduced Version) SAP, generating an EPC 'A' (94 SAP) from 'F' (34 SAP)
Building upgrade includes PV's, Battery, triple-glazing, super-insulation, natural ventilation regime, all resulting in a reduced annual total energy use to 36KWhrs/m^2/year, 86% less energy consumption than the average UK home.
Calculated Operational Whole Life Carbon over 60years is 21% lower than the UK NZCBS at 1,256 kgCO2e/m^2 (Carbon Intensity 40kgCO2e/m^2/year)
Low VOC (Volatile Organic Compounds) specification and natural ventilation regime improved IAQ (Indoor Air Quality) with PM2.5, PM10 and HCHO(Formaldehyde) below World Health Organisation (WHO. 2007) thresholds.

WHAT'S NOT INCLUDED IN NUMBER 23

Unusually, this property can usefully be described by citing what's not included, rather than what is. There are no fossil fuels used, no gas nor oil boiler, no radiators, no pipework, no balanced flue, no TRV's, no MDF, no

carpets, no floor vinyl, no MVRH, no air-source, no ground-source heating, no mechanical ventilation and almost no embedded VOC's.

ENERGY CONSUMPTION

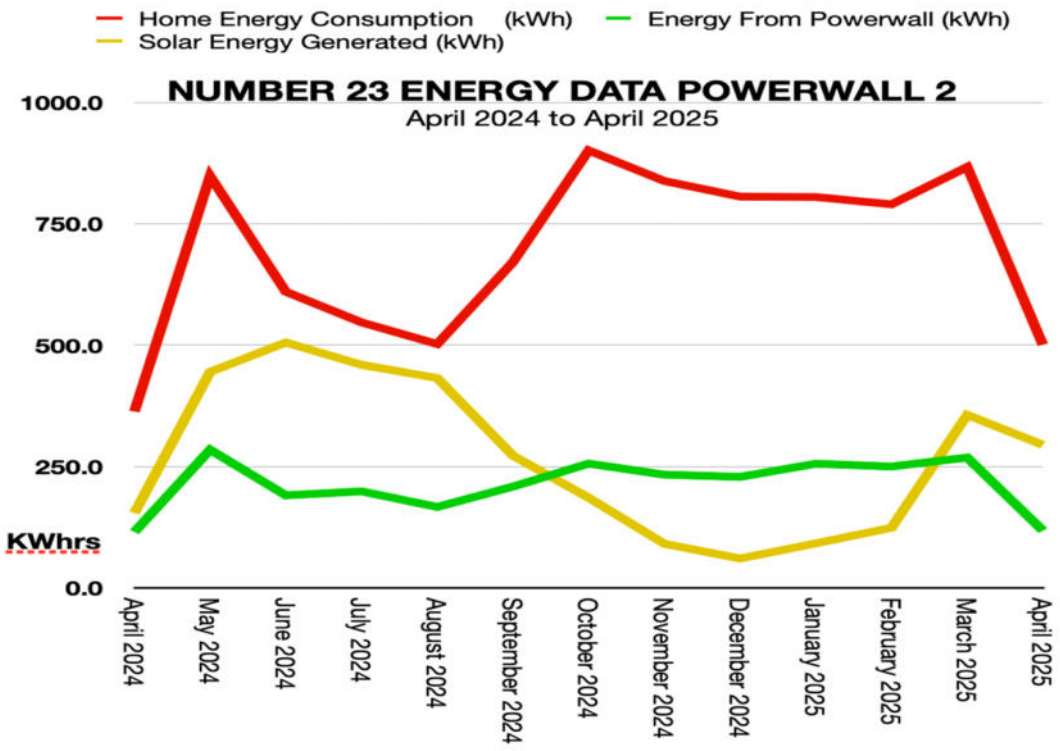
Between April 2024 to March 2025 total household energy consumption, excluding EV charging, was 3,457KWhrs (36 kWh/m²/year) sourced from Octopus bills, Tesla Gateway and building performance sensors.
In 2024, the average East of England total household energy consumption reported by Utility Bidder, was 251KWhrs/m^2. Number 23's annual energy consumption is 86% less than the average East of England home.

INDOOR AIR QUALITY (IAQ) AT NUMBER 23

Measured IAQ, PM2.5, PM10 and HCHO at Number 23 are below the WHO thresholds providing 'good' indoor air quality at this home.

LIFE CYCLE ANALYSIS (LCA)

Full calculation can be downloaded from Dropbox folder NUMBER 23 LCA CALCULATION carried out in accordance with the RICS Whole Life Carbon Assessment Standard (Version 2) and EN 15978.
Number 23's WLC performance warrants describing as exceptional, the LCA metrics surpass the **Low Energy Transformation Initiative (LETI) 2030 Design Target (<300 kgCO₂e/m² A1-A5)** sitting comfortably in **Band A**.
The home also surpasses **the RIBA 2030 Built Target (<625 kgCO₂e/m² A1-5, B1-5, C1-C4)** and outperforms the current **Pilot UK Net Zero Carbon Buildings Standard (NZCBS) (<270 kgCO₂e/m² A1-A5)**
Operational emissions of **6.3 kgCO₂e/m²/year** significantly surpasses the **UK NZCBS best-practice** of **<8 kgCO₂e/m²/year.**



Graph 1: Number 23 Energy Consumption, Generation & Storage

REFERENCES

World Health Organisation. (2007), WHO Guidelines For Indoor Air Quality: Selected Pollutants ISBN 978 92 890 0213 4

CONFERENCE TOPIC

TECHNOLOGIES & SYSTEMS;- Sustainable Renovation & Energy Retrofits

GREENHOUSE RENEWABLE ENERGY HEATING, COOLING AND DEHUMIDIFICATION: A CASE STUDY FOR LESOTHO

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SUMMARY

The viability of an energy-sustainable greenhouse in Lesotho and notably, solar photovoltaic thermal (PVT) assisted greenhouse heating, cooling and dehumidification in weather conditions in Lesotho is established. Results for solar PVT assisted temperature regulation incorporating thermal load assessment, dehumidification modelling, and whole system simulation are presented for two representative locations analysed: Leribe in the lowlands, noted for being the agricultural site in Lesotho, and Mokhotlong in the highlands, typified by cooler weather and prolonged heating needs. The proposed solar PVT-assisted approach supported solar fractions of 87.6% in Leribe and 80.6% in Mokhotlong; energy savings of 6,764–6,936 kWh/year and CO_2 reductions of 1,740–1,944 kg/year; Net Present Values above US$ 53,000, Savings-to-Investment Ratios exceeding 3.0, and a discounted payback period of five years. The study results are encouraging and the next step is to set up a trial on a significant scale to further confirm the merits of solar PVT-assisted greenhouse microclimate control.

Keywords: Solar photovoltaic thermal (PVT); Renewable heating, renewable cooling, renewable dehumidification; energy sustainable greenhouse.
Acknowledgements: *Project SOLTRAIN+ funded by the Austrian Development Agency (ADA) with funds of Austrian Development Cooperation*

INTRODUCTION

Lesotho's agricultural sector faces pressing sustainability and productivity challenges due to recurring climate-induced shocks such as droughts, delayed rains, unseasonal snowfalls, late frosts, flash floods, hailstorms, and rising energy costs. Climate-resilient facility agriculture, and in particular energy-sustainable greenhouses, presents a promising solution for ensuring consistent agricultural productivity and enhancing food and nutrition security under Lesotho's extreme weather. This study investigates the viability of solar photovoltaic thermal (PVT)-assisted greenhouse heating, cooling, and dehumidification under Lesotho's unique weather conditions, with Leribe (lowlands) and Mokhotlong (highlands) selected as representative case study locations.

METHODS

The study methodology combined mathematical modelling, simulation, and economic analysis to evaluate the feasibility of a solar-assisted greenhouse system in Lesotho. A thermal model was developed to estimate heating and cooling demands based on greenhouse energy balances, accounting for heat gains from solar radiation, conduction, convection, and ventilation losses. A separate dehumidification model quantified moisture loads by analysing evapotranspiration, condensation, and air exchange rates to predict additional dehumidification requirements. System performance was then simulated in Polysun software, which enabled configuration of collectors, storage, and control strategies under site-specific climate data to assess solar fraction, energy savings, and emissions reduction. Finally, an economic analysis integrated capital, operational, and maintenance costs with revenue from tomato production, applying financial indicators such as Net Present Value, Savings-to-

Investment Ratio, Levelised Cost of Energy, and payback period, with sensitivity tests on yield, price, and CAPEX to assess robustness of results.

RESULTS AND DISCUSSIONS

Thermal and moisture modelling revealed that the greenhouse solar PVT-assisted heating, cooling and dehumidification provide a strong renewable contribution, with solar fractions of 87.6% in Leribe and 80.6% in Mokhotlong. Annual collector yields ranged between 127.5 and 130.5 kWh/m², translating into energy savings of 6,764–6,936 kWh/year and CO_2 reductions of 1,740–1,944 kg/year. Heating requirements were notably higher in Mokhotlong due to its prolonged cold season, while cooling and dehumidification needs were more pronounced in Leribe. The modelling further demonstrated that shading configurations play a crucial role in lowering cooling demands, with dark green shading reducing loads to near-zero levels in Mokhotlong. These findings emphasize that system design must be site-specific, reflecting both thermal demand and operational profiles. The economic assessment confirmed the financial feasibility of adopting PVT-assisted greenhouse systems. Across both sites, Net Present Values exceeded US$53,000, with Savings-to-Investment Ratios greater than 3.0 and discounted payback periods averaging five years. Sensitivity analysis showed that profitability is most influenced by crop yield and market price, which shifted NPV by approximately ±30%, while capital expenditure played a comparatively minor role. These results establish solar PVT-assisted greenhouse systems as not only technically reliable and environmentally advantageous, but also economically sustainable for agricultural enterprises in Lesotho.

CONCLUSIONS AND RECOMMENDATIONS

This study established that solar-assisted greenhouse climate control presents a viable pathway for energy sustainable agriculture in Lesotho. By integrating thermal modelling, dehumidification analysis, and system simulations, the research demonstrates that such systems can effectively address greenhouse heating, cooling and dehumidification requirements while reducing reliance on conventional energy sources. The approach offers clear environmental benefits through emissions reduction and supports long-term economic sustainability, as the systems were found to deliver positive investment returns. Importantly, the findings underline the need for site-specific design considerations. Overall, the study highlights the potential of solar-assisted greenhouse technologies to enhance agricultural resilience, support food security, and provide a replicable framework for similar climate-challenged regions.

REFERENCES

B. A. Jafino, B. Walsh, J. Rozenberg, and S. Hallegatte, ‘‘Revised Estimates of the Impact of Climate Change on Extreme Poverty by 2030’’, World Bank Policy Res. Work. Pap., no. 9417, Sep. 2020. doi: 10.1596/1813-9450-9417.

C. Nhemachena et al., ‘‘Climate Change Impacts on Water and Agriculture Sectors in Southern Africa: Threats and Opportunities for Sustainable Development’’, Water, vol. 12, no. 10, p. 2673, Sep. 2020. doi: 10.3390/w12102673.

A. Yano and M. Cossu, “Energy sustainable greenhouse crop cultivation usig photovoltaic technologies’’, Renewable and Sustainable Energy Reviews, vol. 109, pp. 116-137. doi: 10.1016/j.rser.2019.04.026.

CONFERENCE TOPIC

WHAT DIFFERENCE A BATTERY MAKES!
BRIDGING THE GAP TOWARDS ENERGY AUTONOMY

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SUMMARY

This is a sequel paper to the case study of nine naturally heated, naturally ventilated UK homes, presented at ISEC 2024. In the interim period, a battery and hybrid inverter installation on April 16th 2025 to one of the nine homes has reduced the three year daily average energy bill from 35pence/day to zero. No energy bills, instead a daily export revenue. The paper shares the first six months performance data, with early indications that No.7 Howgate Close may be on a journey in achieving energy autonomy. Should the Abstract expand in to a full paper, nine months of performance data will be disseminated.

INTRODUCTION

This paper is a sequel publication to the ISEC 2024 paper, *'A CASE STUDY OF NINE POST-HYDROCARBON READY HOMES; Summarising In-Use Building Performance Data, Benchmarking Against UK Building Regulation Standards.'* As pledged in the 2024 paper, this 2026 paper is a more forensic analysis of No.7 Howgate Close, with the benefit of a battery and hybrid inverter installation.

Over the first three years of occupation, the selected 1bed home has recorded exceptionally low average daily total energy costs, a performance typical of all nine Howgate homes. Each of the nine homes average daily energy bills are less than 45pence/day (inclusive of Standing Charge) Before the battery install, No.7's average daily energy consumption was 7KWhrs/day imported energy from the grid while exporting 13.5KWhrs/day to the grid.

It is planed that the next stage of Howgate Close's development is the inclusion of energy storage facilities to all nine homes. However, the first phase has been to install an 11KWhr BYD battery and a Fronius hybrid inverter to a 1bed dwelling (No.7) with the purpose of informing the specification of the balance of eight units.

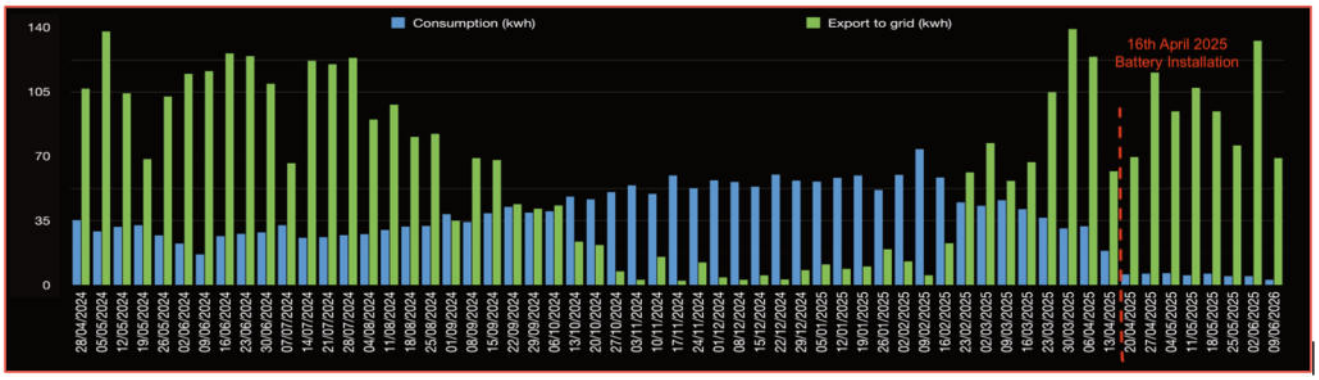
PERFORMANCE RESULTS

No.7's results from 16.04.2025 to 15.06.2025 record in excess of 50% reduction in daily energy consumption from the grid, compared to the same period in 2024. For the full paper, No.7's 9months energy profile from April 16th 2025 to January 15th 2026 are to be included.

For the period from 12th July to 13th August 2025, 18KWhrs electricity were imported from the grid (2.5kWhrs/day) and 298kWhrs (42kWhrs/day) were exported to the grid in the same period of time.

Comparing the data from the same period in 2024, 117kWhrs were imported from the grid and 480kWhrs exported to the grid. 99kWhrs less imported, an 85% reduction in energy consumed from the grid and 190kwhrs less exported, a 38% reduction in exported energy.

Despite the presence of the 11kWhr battery, the 1bed still imports energy from the grid on a daily basis. Peak demand for energy occurs regular pattern from 7am for approximately an hour and again around 6pm for another hour. These spikes in energy demand are understood to derive from the combined uses of the following electrical appliances, a 9kW shower, 5kW oven, 3kW kettle and 2kW air fryer in addition to other devices e.g. computers, TV, Smart Metre, router.



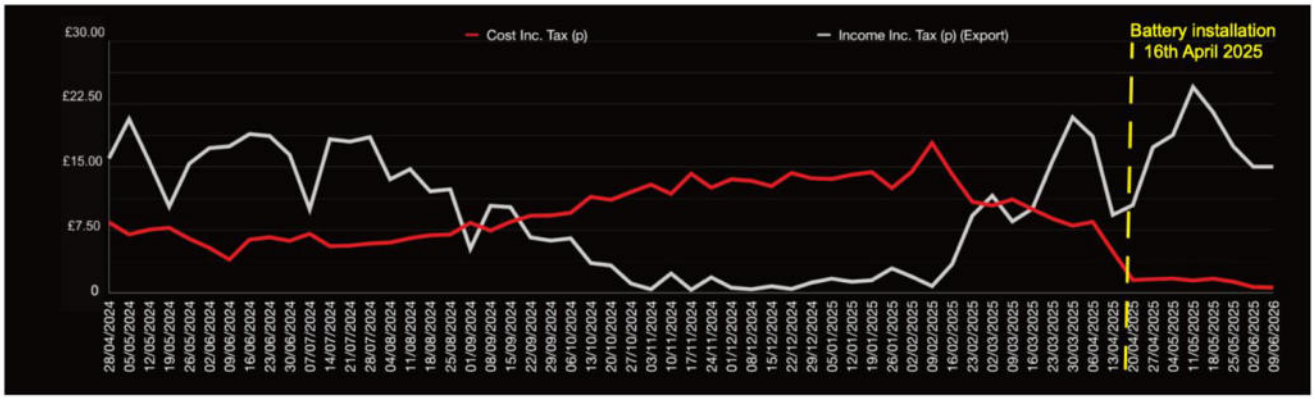
Bar Chart. 1: No.7 Howgate Close Energy Imported & Exported

BATTERY ENERGY STORAGE INSTALLATION

On 16th April 2025, at the 1bed home, no.7 Howgate home, the existing Fronius Primo 4.6kW inverter was replaced with Gen24 Primo 4.5kW inverter and BYD HVM 11kWh battery. From 16th April to 13th August 2025, the property has been 93% self-sufficient with 434kWh additional benefit from battery storage and 72kWhrs drawn from the grid due to short periods of high loads.

With a battery installed, the first 120days of installation, over 1.58MWhrs of renewable energy generated from the roof mounted pv's was exported. 59% of the renewable energy generated was still exported despite the presence of the battery. Data from July 2024 and 2025 shows higher generation in 2025, probably due to better insolation. What difference a battery makes?

No.7's performance data reinforces the role of batteries in buildings, as '*reservoirs of energy'*.



Graph. 1: No.7 Howgate Close Energy Costs, Pre & Post Battery Installation

REFERENCES

Harrall. J. (2023). Reservoirs of Heat: A defining characteristic of high thermal mass earth-sheltered buildings.18th World Conference of ACUUS: Advances in Underground Space Development. Singapore

CONFERENCE TOPIC

PREDICTING SOLAR THERMAL POWER PLANT YIELD USING PHYSICS-BASED AND MACHINE LEARNING-BASED MODELS

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SUMMARY

This work presents a comprehensive study comparing the performance of basic physics-based models, classic machine learning models, and advanced neural network architectures for minute-by-minute yield prediction in solar thermal power plants. Using an open-source dataset, we evaluate these models across different feature sets (weather-only vs. weather and measurement data), seasonal train-validation-test splits, and varying amounts of training data. Our results reveal that neural networks outperform physics-based models, and that weather data alone can achieve satisfactory performance. Furthermore, hybrid approaches (combining physics-based models with machine learning) improve over pure physics-based models, however, do not surpass standalone machine learning models. Finally, we investigate the transferability of pre-trained neural network models to other solar thermal power plants, demonstrating promising generalization capabilities, especially for one of the new plants.
Keywords: solar thermal power plants, yield prediction, physics-based models, machine learning

THE YIELD PREDICTION CHALLENGE AND THIS WORK'S FOCUS

Accurately predicting the yield of solar thermal power plants is essential for optimizing energy planning, ensuring economic viability, and accelerating the transition to renewable energy, and machine learning techniques have emerged as a promising tool for this task. However, yield prediction remains challenging due to the operation of a solar thermal power plant depending on a complex interplay of factors, including external factors such as solar irradiance, ambient temperature, and internal factors, like the inlet and outlet temperatures of the heat transfer fluid.

While prior studies have shown that both physical and machine learning models can perform reasonably well at predicting yield of a solar thermal power plant, issues such as reliance on proprietary data and limited experimental scope persist, making it difficult to compare algorithms. This work addresses these limitations by conducting a large-scale, transparent comparison of basic physics-based models, classic machine learning models, and neural network architectures (e.g., GRU and LSTM) for predicting minute-by-minute yield. Minute-by-minute yield prediction involves predicting yield for each minute of a given time series based on the current minute's features and potentially incorporating historical data from a predefined lookback period.

Using an open-source dataset (Tschopp et al., 2023), we evaluate these models for minute-by-minute prediction on two feature sets (weather-only and weather with measurement data) across different train-validation-test splits (summer, winter, and random), varying lookback periods, and lengths of the training data (one, two, or four months). This comprehensive approach aims to provide actionable insights into the strengths and limitations of different modeling techniques for solar thermal yield prediction.

RESULTS

Our results show that the amount of training data significantly impacts performance, with models trained on winter data performing worse than those trained on summer or random data. For example, restricting training to one month of data yields R^2_{val} scores of 79.3%, 90.8%, 95.9% for weather-only features and 89.3%, 97.2%, and 99.1% for measurement features, for winter, summer, and random splits, respectively (cf. Figure 1). Extending the training to two or four months reduces these differences. Neural networks, particularly GRU and LSTM, outperform other models except in the most restricted winter training scenarios. Adding system-specific variables (e.g., volume flow and inlet temperature) improves generalization but is not essential, as weather data alone achieves satisfactory performance. This is advantageous for maintenance, as weather data is more accessible and can incorporate forecasting information.

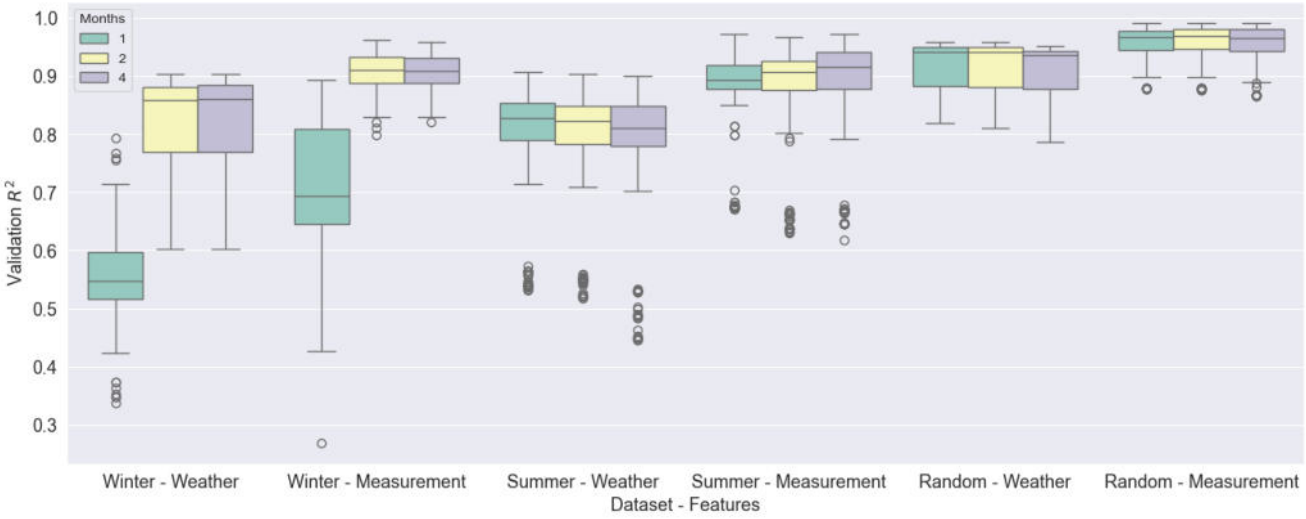


Fig. 1: Boxplot of validation R^2 values of different models grouped by dataset, features, and months of training.

As baseline, the results are compared to a simple physics-based model based on the ISO 9806:2017 formula A.2 using the conversion method of ISO 9806:2017 Annex B and setting $a_3, a_4, a_5, a_6 = 0$:

$$\dot{Q}_{col} = \eta_{0,hem} \cdot K_{hem}(\theta_T, \theta_L) \cdot G_{hem} - a_1 \cdot (\vartheta_{col} - \vartheta_a) - a_2 \cdot (\vartheta_{col} - \vartheta_a)^2 \quad \text{(Equation 1)}$$

Here, G_{hem} denotes the hemispherical global irradiance on the plane of the collector, $\eta_{0,hem}$ denotes the peak collector efficiency based on hemispherical irradiance, ϑ_{col} the collector mean temperature, ϑ_a the ambient temperature, K_{hem} the incidence angle modifier for hemispherical irradiation, and a_1 and a_2 denoting the first and second order heat loss coefficients of the collector.

We also explore hybrid models by combining physics-based approaches with machine learning. For example, learning the residuals of a physics-based model (Equation 1) using the weather-only features and a GRU or using the weather plus measurement features and an LSTM improves R^2_{val} scores to 72.4%, and 92.4%, respectively, compared to 62.6%, for the pure physics-based model (cf. Figure 2). However, these hybrid models do not outperform standalone machine learning models in this setting.

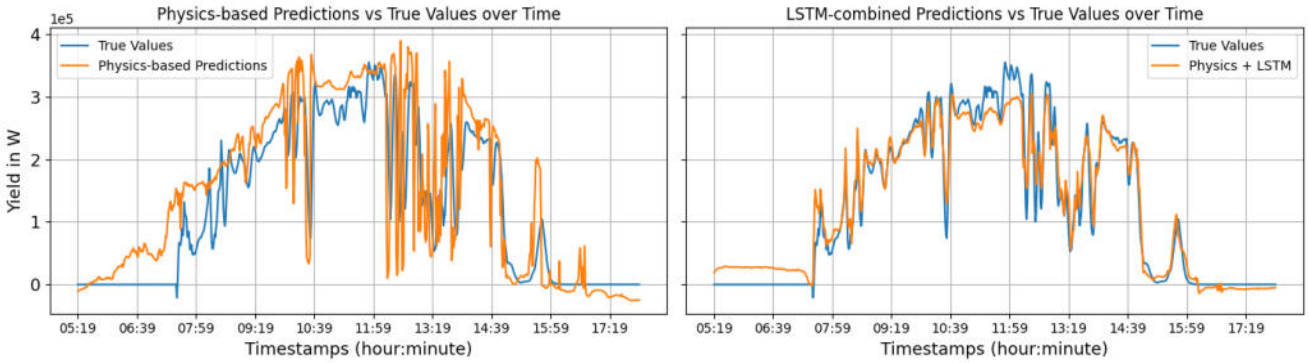


Fig. 2: Comparison of prediction quality, only physics-based (left) and combined with LSTM (right) (in 2017-05-02)

Finally, we assess the transferability of pre-trained neural networks to two other solar thermal plants. Despite differences in data characteristics, the GRU model achieves R^2_{val} scores of 31.1% and 69.3% for two new plants, while the LSTM model achieves -209.8% and 79.9% (cf. Figure 3). The differences in transferability are indicative of variation in 1) climatic conditions related to the power plant's location (e.g., whilst the statistics for ambient temperature are comparable to the second plant ($\bar{\vartheta}_a^{Open-source} = 283.9\,K, SD\left(\vartheta_a^{Open-source}\right) = 9.8\,K, \bar{\vartheta}_a^{Plant\,2} = 284.0\,K, SD\left(\vartheta_a^{Plant\,2}\right) = 9.2\,K$), they differ substantially from the first one ($\bar{\vartheta}_a^{Plant\,2} = 301.8\,K, SD\left(\vartheta_a^{Plant\,2}\right) = 2.1\,K$)) and 2) the internal characteristics of the analyzed plants. Systematic differences in both 1) and 2) are likely to hinder generalizability since the model learns the specific characteristics of the solar thermal power plant the pre-trained model is based on, explaining the poor results for the LSTM model for the first plant. These results demonstrate the feasibility of foundational models for new installations in case of comparable characteristics.

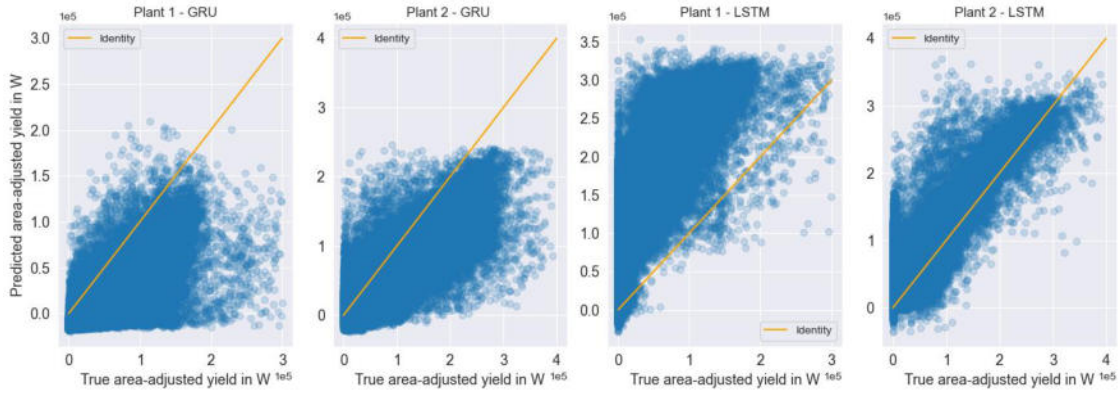


Fig. 3: GRU and LSTM predictions versus true yield for both new power plants, clipped

CONCLUSIONS AND FUTURE WORK

In summary, this work shows that neural network models, particularly GRU and LSTM, outperform both physics-based and classic machine learning models in predicting minute-by-minute solar thermal power plant yield. These models generalize well across seasonal and random splits, with weather data alone often being sufficient for high accuracy, simplifying practical applications. Hybrid approaches combining physics-based and machine learning models improve over pure physics-based models but do not surpass standalone machine learning models. Additionally, pre-trained neural networks demonstrate promising transferability to other solar thermal power plants, highlighting the potential for foundational models that generalize across installations.

Future work could focus on pre-training models on data from multiple plants to improve generalization, integrating weather forecasts for forecasting capabilities, and adopting online learning to adapt to changing conditions. Combining machine learning with advanced physics-based simulations could also yield hybrid models that better capture system dynamics, paving the way for more robust and scalable yield prediction systems.

REFERENCES

Tschopp, D., Ohnewein, P., Stelzer, R., Feierl, L., Hamilton-Jones, M., Moser, M., & Holter, C. (2023). One year of high-precision operational data including measurement uncertainties from a large-scale solar thermal collector array with flat plate collectors, located in Graz, Austria. *Data in Brief, 48*, 109224. https://doi.org/10.1016/j.dib.2023.109224

CONFERENCE TOPIC

The abstract refers to the conference topic 2.02. IT Solutions and Artificial Intelligence.

TOPOLOGICAL ANALYSIS OF FRENCH DISTRICT HEATING NETWORKS FLEXIBILITY

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SUMMARY

Keywords: district heating networks, topological analysis, clustering, flexibility

District heating networks (DHN), which can heat buildings more efficiently at a lower cost and are more easily coupled with renewable and recovered energies, are multiplying, spreading, and evolving towards low temperature. Consequently, integration of distributed energy sources appeals for defining their energetic flexibility potential as a function of their characteristics, such as their topologies. The proposed method uses graph theory to develop topological analysis tools to characterise, classify and explain network topologies. Results show the approach's relevance (in particular that of the extracted characteristics) to explain DHNs.

INTRODUCTION

DHNs show promise as a replacement for traditional heating systems: centralized heat production implies a better handling of energy resources and a proportionally lesser installed heating power. Given this context, a better characterisation of networks through relevant and objective indicators appears necessary. This can be done through network topology. Suggestions have been made for optimal topologies for new networks, but characterisation of existing topologies remains needed to promote their evolution. The method proposed in this article aims to characterize, classify and explain network topologies through the use of graph theory. Based on real-world data, characteristics are determined, then used to classify networks.

DATA

This work uses open data on French DHNs: France Chaleur Urbaine for the network layouts; and the local heat and cold consumption data published by the French SDES (statistical studies and data service). Due to imprecise or incorrect layouts, a lengthy correction process is required. After cleaning the data of missing and incoherent values, a consolidated database of 442 networks across France is considered in the study. The data is preprocessed to regroup energy sources, keeping total, non-renewable, dispatchable renewable and non-dispatchable renewable productions. The original number of energy sources is also added to the data.

METHODOLOGY

NETWORK CHARACTERISATION

Several characteristics are extracted from the data: some energetic, such as the installed power or number of heat delivery points; other topologic, such as network length. Other characteristics are then computed, such as load factor, linear heat density, fractal dimension or average pipe diameter.

FLEXIBILITY INDICATORS

Flexibility indicators are constructed to numerically represent the flexibility of each network:

$Fl_P = \frac{1}{\sum_{i=1}^{n} p_i^2}$ The production flexibility indicator, with $p_1, \ldots, p_n$ the respective proportion of each production source, shows how independent each network is from its energy sources (eq. 1)

$Fl_C = \frac{\#HD}{\sigma_C}$ The consumption flexibility indicator, with $\#HD$ the number of heat delivery points and σ_C the consumption standard deviation across sectors, shows the consumption profiles diversity (eq. 2)

$Fl_D = \frac{l + l_{loop}}{diam}^{Fd}$ The distribution flexibility indicator, with l the network length, l_{loop} the length of the loops, $diam$ the graph diameter and Fd the fractal dimension, shows network resiliency (eq. 3)

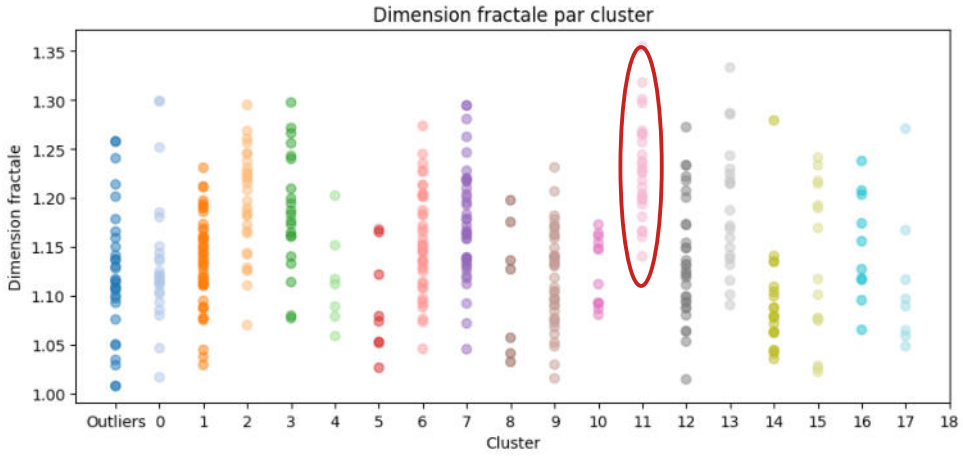
$Fl_S = c\frac{d^2 \pi l}{C_h}$ The storage flexibility indicator, with d the average pipe diameter, C_h the average hourly consumption and c constant for all networks, shows preheating capability (eq. 4)

NETWORK CLUSTERING

Since indicators have widely varying orders of magnitude, they are mapped onto a 2D plane. Then, DBSCAN [1], a clustering algorithm that allows outliers and requires no hypothesis about clusters, classifies the networks.

NETWORK CLUSTER EXPLAINING

Using causal inference [2], the network clusters are explained based on the networks' energetic and topological characteristics, allowing for recommendations to improve network flexibility by tuning root cause indicators.



RESULTS

Fig. 1: The fractal dimension across clusters. Cluster 11 is visibly linked to relatively higher fractal dimensions.

Energetic and topological indicators have been calculated and the networks classified based on their fractal dimension, number of loops, length and creation year. Some clusters seem largely dependent on one indicator (such as cluster 11 in Fig. 1) but most remain unexplained, highlighting the need for causal inference. The causal discovery algorithm finds fractal dimension, number of loops and length to be closely related. Length and creation year appear as two unrelated causes for the clusters.

CONCLUSION

This work offers a new methodology to study urban heat network topologies. Going forward, the four flexibility indicators can be included in the clustering and the causal inference can be applied globally to determine all cause and effect links within the data.

REFERENCES

[1] Martin Ester et al. "A density-based algorithm for discovering clusters in large spatial databases with noise". In: kdd. T. 96. 34. 1996, p. 226-231.

[2] Judea Pearl. Causality. Cambridge university press, 2009.

CONFERENCE TOPIC

This abstract refers to the Conference Topics 1.07 Flexibility and Stability in Thermal an

INNOVATIVE THERMAL STORAGE FOR HIGH TEMPERATURE INDUSTRY DECARBONATION – HEATERNAL EU PROJECT

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SUMMARY

The objective of HEATERNAL project is to develop a system which would recover industrial waste heat to replace natural gas, reducing carbon emissions and improving efficiency of industrial thermal processes. This innovative high temperature (>500°C) thermal energy storage (TES) system should contribute to a high-level integration of renewable energy into industrial processes. Two key components are considered: (i) innovative phase-change materials integrated into a design to amplify the energy density by 350%, and (ii) manufacturing proficiency that guarantees swift integration of the whole system into factories by 2030. Due to this, a thermal simulation was conducted and new phase change materials were characterized and integrated into a unit design based on a thermo mechanical model.

Keywords: thermal energy storage, phase change material, ceramic, high temperature, energy density

INTRODUCTION

According to the European Environment Agency, industrial processes in Europe released 1.13 billion tonnes of CO_2 equivalent in 2023, 15% less than in 2022. Heating accounts for 17% of energy consumption in industry, mainly using Natural Gas, and 20-50% of this heat is lost to surroundings [1,2]. To face climate change and geopolitical crisis, storage and recovery of energy, industrial heat-waste limitation and use of renewable energies are strategic technologies to be developed by 2030. Numerous industrial processes require continuous high-temperature heat, and currently, no viable solution for decarbonizing these processes exists. The implementation of a thermal energy storage, lasting up to 48 hours could facilitate the substitution of fossil fuels with industrial recovered heat and renewable energy.

SCOPE OF THE PROJECT

HEATERNAL project develops a solution based on hybrid storage using refractory ceramics and phase change materials (PCMs) to meet the industrial needs of continuous high temperature heat (Fig.1). This storage ought to operate between 600 and 900°C with 3 temperature zones. In order to increase the energy density of the system, several PCMs with different melting temperatures and latent heat of fusion are proposed to implement a cascading effect. The PCM composition is adjusted to comply with the targeted industrial applications. HEATERNAL project addresses 2 technologies for the refractory material: the traditional one based on casted bricks and a more prospective technology based on additive manufacturing.

The project activities focus on the development and characterisation of new high-temperature PCMs and the thermo-mechanical modelling of the TES in order to optimise the design of the TES unit. The project team will produce a 50 kWh functional prototype along with storage system models tailored for factory integration. The project also aims at ensuring the economic viability and environmental sustainability of the system while minimizing system footprint.

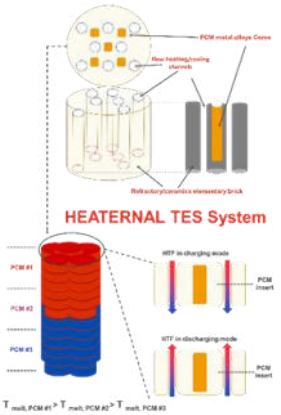


Fig.1: HEATERNAL concept for high-temperature hybrid ceramic-PCM thermal storage

THERMO- MECHANICAL MODELLING

A main task regarding the modelling methodology has been carried out to define the design of the elementary bricks and later the full TES unit. Based on materials physical properties, the air flow, tubes dimensions and repartition were defined in accordance with the industrial use case. Later, the calculated thermal field was used to assess the thermo-mechanical stress in the refractories during the operation of the prototype. The methods are based on structural analysis taken from temperature and stress fields obtained by the finite element Ansys suite (Fluent and Mechanical). The geometries feature the complete stack of bricks and the stresses are evaluated based on the maximal and minimal principal stress in the material. However, due to the difference in thermal expansion of the PCM and the refractory material, an adaptation of the geometry where the PCM is divided into several segments is proposed.

PCM DEVELOPMENT

The project is focusing on metallic alloys as PCMs due to their superior properties compared to salts or organic materials. Metallic PCMs demonstrate high thermal expansion, high thermal conductivity, relatively low vapor pressure, and quite high latent heat of fusion (all these characteristics are crucial for high-temperature applications). Looking at the literature [3], Al-based and Cu-based alloys are the two main groups covering our target temperature range. However, to meet the operating conditions of HEATERNAL, materials properties need to be refined and that is where silicon plays an important role. Silicon makes it possible to adjust the melting temperature: reducing Si and increasing Al ratio lowers the melting point and increasing Si ratio lowers the coefficient of thermal expansion. For this, four PCMs with different melting points, ranging from 550°C up to 850°C, have been selected from literature [4–6] and CALPHAD calculations. The PCMs were synthetized in a high-frequency induction furnace, using a cold copper crucible under vacuum atmosphere. After an optimal selection, the synthesised alloys were analysed thanks to a variety of methods to obtain a complete thermo-mechanical characterisation.

This research is part of a large European project, HEATERNAL, whose main ambition is to meet the industry needs of a constant high temperature heat in the face of climate and geopolitical urgencies. This document has been prepared within the framework of IEA ES TCP. This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101103921, HEATERNAL.

REFERENCES

[1] I. Ortega-Fernández, J. Rodríguez-Aseguinolaza, Thermal energy storage for waste heat recovery in the steelworks: The case study of the REslag project, Applied Energy 237 (2019) 708–719. https://doi.org/10.1016/j.apenergy.2019.01.007.

[2] A.I. Fernández, C. Barreneche, L. Miró, S. Brückner, L.F. Cabeza, 19 - Thermal energy storage (TES) systems using heat from waste, in: L.F. Cabeza (Ed.), Advances in Thermal Energy Storage Systems, Woodhead Publishing, 2015: pp. 479–492. https://doi.org/10.1533/9781782420965.4.479.

[3] S.C. Costa, M. Kenisarin, A review of metallic materials for latent heat thermal energy storage: Thermophysical properties, applications, and challenges, Renewable and Sustainable Energy Reviews 154 (2022) 111812. https://doi.org/10.1016/j.rser.2021.111812.

[4] S. Khare, M. Dell'Amico, C. Knight, S. McGarry, Selection of materials for high temperature latent heat energy storage, Solar Energy Materials and Solar Cells 107 (2012) 20–27. https://doi.org/10.1016/j.solmat.2012.07.020.

[5] B. Hallstedt, J. Gröbner, M. Hampl, R. Schmid-Fetzer, Calorimetric measurements and assessment of the binary Cu–Si and ternary Al–Cu–Si phase diagrams, Calphad 53 (2016) 25–38. https://doi.org/10.1016/j.calphad.2016.03.002.
[6] A.I. Fernández, C. Barreneche, M. Belusko, M. Segarra, F. Bruno, L.F. Cabeza, Considerations for the use of metal alloys as phase change materials for high temperature applications, Solar Energy Materials and Solar Cells 171 (2017) 275–281. https://doi.org/10.1016/j.solmat.2017.06.054.

CONFERENCE TOPIC

1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage.

APPLICATION OF SMART THERMAL MONITORING AND CONTROL SYSTEM (STMACS) FOR SOLAR WATER HEATING SYSTEM INSTALLATIONS: A CASE STUDY

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SUMMARY

The Smart Solar Thermal Monitoring and Control System aims to enhance the efficiency and reliability of solar thermal installations by integrating temperature and flow sensors, microcontrollers, and communication technologies such as Wi-Fi and GSM. It monitors system performance, manages thermal storage, detects faults, and implements predictive heating to ensure hot water is available when needed while reducing energy waste. The system features a dashboard for remote monitoring and automated control of pumps and valves. The methodology involves initial simulation using Proteus, followed by hardware prototyping with Arduino, sensor integration, and iterative testing for validation. Data collected from sensors is processed intelligently to optimize operations and trigger alerts when anomalies occur. This approach provides a cost-effective, smart solution for small- to medium-scale solar thermal systems.

Keywords: smart, IoT, Arduino, Solar thermal, thermal storage, sensors

INTRODUCTION

Solar energy systems, particularly solar thermal technologies, have become an essential part of sustainable energy solutions worldwide. These systems are widely used for heating water, generating electricity, and other energy applications, especially in regions with high solar irradiance (Kumar et al., 2022). However, maintaining their efficiency and ensuring their long-term performance remains a major challenge. Traditional monitoring and maintenance methods are often reactive, addressing faults only after significant system failures or efficiency losses have occurred.

To address these challenges, intelligent monitoring and control systems have emerged as a reliable approach. By utilizing sensor data, these systems can track key performance indicators such as temperature, pressure, and flow rate in real-time, ensuring optimal energy conversion and distribution (Atofarati and Enweremadu, 2025). More advanced systems not only monitor performance but also detect anomalies early, enabling **preventive maintenance** rather than waiting for costly breakdowns. In addition, predictive control features, such as forecasting heating needs, enhance energy efficiency and system reliability. The integration of Internet of Things (IoT) technologies has further advanced solar monitoring systems. IoT enables real-time data collection, remote access, and automated control, ensuring that performance information is continuously available to system operators. This connectivity improves decision-making, enhances failure detection, and allows for immediate response to inefficiencies (Solar, 2025). The proposed **Solar Thermal Monitoring and Control System** builds on these innovations by combining intelligent sensor-based monitoring, preventive and predictive fault detection, and remote access capabilities. By ensuring both reliability and efficiency, the system offers a comprehensive solution to improve the performance and longevity of solar thermal installations. The specific objectives include:

- To design a sensor-based monitoring system that collects data from temperature, flow, and pressure sensors for accurate system assessment.

- To implement predictive heating algorithms that optimize water temperature according to user demand patterns and environmental conditions.
- To incorporate preventive fault detection to identify anomalies before they lead to system failures, minimizing downtime and maintenance costs.
- To develop a remote monitoring interface (dashboard) that allows users or administrators to track system performance, receive alerts, and make informed operational decisions.

STUDY METHODOLOGY

This methodology outlines the systematic approach to developing the Solar Thermal Monitoring and Control System. The study aims to design an intelligent system capable of monitoring solar water heating processes, detecting faults, managing predictive heating, and displaying real-time data on a dashboard. The approach includes both simulations using Proteus and hardware. The initial design involves connecting sensors to the microcontroller, defining control logic for predictive heating, and configuring output devices for alarms and alerts. Proteus will be used to simulate these connections before physical implementation. A synopsis of the study methodology is presented in Figure 1, while the block diagram of the system is presented in Figure 2.

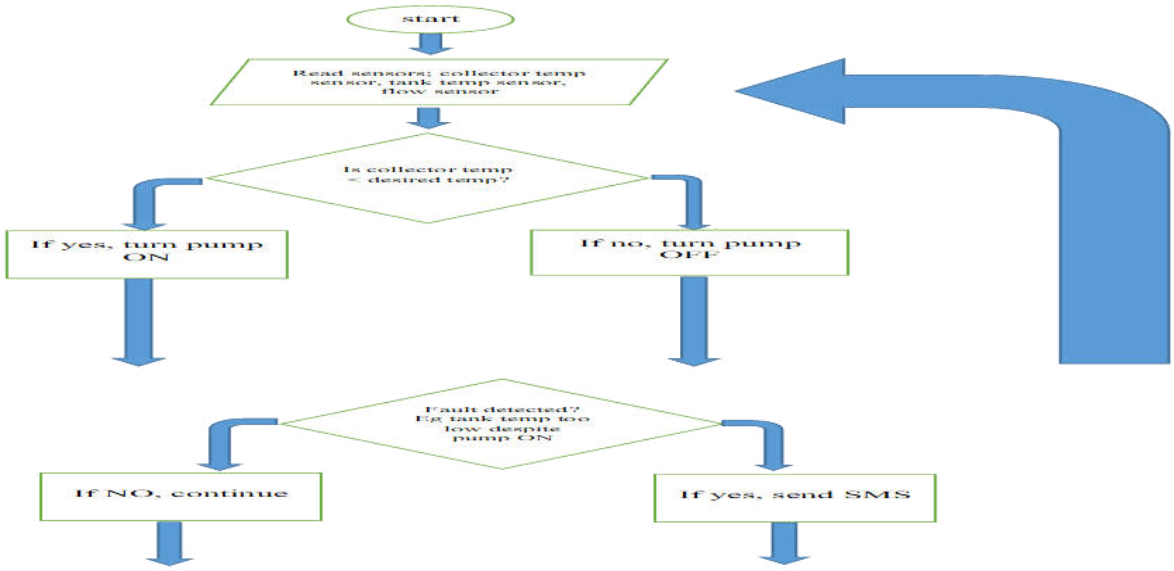


Figure 1: Flowchart of system methodology

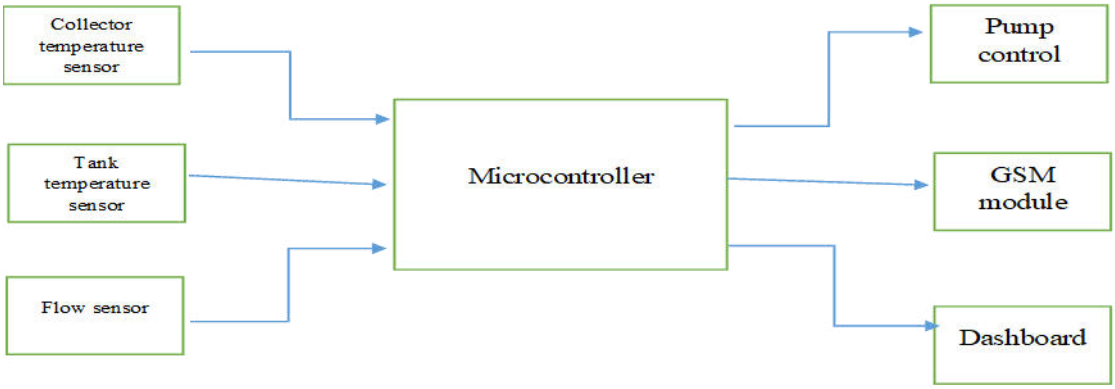


Figure 2: Block diagram of system

REFERENCES

Atofarati, E. O. and Enweremadu, C. C. (2025). "Industry 4.0 enabled calorimetry and heat transfer for renewable energy systems," *iScience*, vol. 28, no. 7, p. 112994, Jun. 2025, doi: 10.1016/j.isci.2025.112994.

Kumar, L., Ahmed, J., Assad, M. E. H., and Hasanuzzaman, M. (2022). "Prospects and Challenges of Solar Thermal for Process Heating: A Comprehensive Review," *Energies*, vol. 15, no. 22, pp. 8501, Nov. [Online]. Available: https://doi.org/10.3390/en15228501

Solar, M. B. (2025). "Solar IoT Integration Transforms PV System Performance and Management," *Moser Baer Solar*, Jul. 18, 2025. [Online]. Available: https://www.moserbaersolar.com/digital-technologies-and-smart-systems/solar-iot-integration-transforms-pv-system-performance-and-management/

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: (2.02) IT Solutions and Artificial Intelligence

FROM FORECASTING TO GRID-FRIENDLY EV CHARGING: FIELD TEST AND OPERATIONAL DATA MANAGEMENT

Ahmad Fayyaz Bakhsh[1], Thomas Kienberger[1], Markus Peyreder[2], Michael Messner[2], Carmen Reiter[2], Andreas Fernbach[3], Joachim Fabini[4], Julia Vopava-Wrienz[1]

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SUMMARY

The overall objective of the project, FriendlyCharge, is the development and demonstration of a customer interface prototype to enable secure on-demand and grid-friendly charging in residential areas. Therefore, nine use cases, defined by combining three types of control and three possibilities of the communication paths, will be analysed in terms of technical, regulatory, and safety-related aspects. Based on this analysis, a field test will be implemented in selected grid areas under real conditions, and one selected use case as main demonstrator. The Operational Data Management (ODM) serves as the central element, integrating key functionalities for communication, residual load forecasting, and dynamic envelope calculation. The forecast model predicts the residual load dynamically and, in combination with dynamic envelopes, determines when charging processes are controlled to relieve the grid.

Key Words: Grid-Friendly-Charging, Operational Data Management, Residual Load Forecasting, Dynamic Envelope Calculation

INTRODUCTION

Traditionally, distribution grids have been built to manage the load flows during peak load hours. Grid reinforcements are used to address local congestion and issues with voltage quality. In the grid planning process, there is growing interest in using flexible resources as an addition to or substitute for the conventional grid infrastructure [1,2]. This step makes the demand and generation management more important. In this context, communication between the grid and flexible resources is essential to ensure reliable interaction and control. At the same time, accurate forecasts are required to enable grid-friendly and on-demand control of flexible resources. In this regard, a promising forecast is of necessary, where historical data is used to forecast the future [3].

One of the most important steps in residual load forecasting is the ability to identify the pattern in the dynamic grids. Several techniques have been used by researchers, such as feature scaling and normalization, to handle different ranges of input variables, and techniques to remove long-term or periodic effects [4,5]. To improve the current studies' performance in this area, the selected model has two mechanisms to deal with this phenomenon. One of them is the forecasting adjustment, and the second one is the rolling window, where new data updates the input sequence to influence future forecasts. The model architecture [6] learns temporal dependencies and complex patterns from historical data (tested on synthetic and measured data) and cyclical features.

This forecasting model is one of the main parts of the demonstrator, with nine different use cases based on the customer interface control and different communication paths. According to this analysis, a field test is established to implement a selected use case. The Operational Data Manager (ODM) serves as the core element, identical across all use cases, integrating communication, residual load forecasting, and dynamic envelope calculation. The forecast model predicts residual load, i.e., the grid load disaggregated from load caused by EV chargers. From these forecasts and the present load threshold value, dynamic envelopes are calculated, which

determine the schedules of charging processes to relieve the grid in a targeted manner. The field test has two main objectives: first, to validate the forecast model under real conditions using live measurements and communication paths, including visual inspection and evaluation metrics, such as Mean Absolute Error and (MAE), and Mean Absolute Percentage Error (MAPE) for on-peak, off-peak, and total periods; and second, to implement, test, and validate the control system for on-demand and grid-friendly charging as well as the required communication and control paths. Preliminary results from synthetic and measured data indicate robustness of the forecast model, while the field test will provide further validation of both model performance and system functionality in real-world conditions.

METHODOLOGY

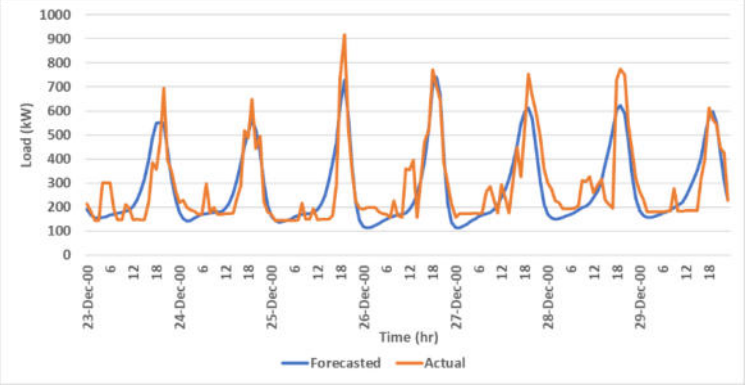
To achieve the project objective of developing and demonstrating a demand-oriented and grid-friendly charging infrastructure, three types of control of the customer interface (direct, EMS, EMS in the cloud) and three possibilities of the communication paths (status quo, hardware device on-site, cloud) are defined, resulting in nine use cases. Each of these is analysed in terms of technical, legal, regulatory and grid-related aspects. During the interface definition (communication and control) process, several 'black boxes' (operating resources and components) are specified depending on the respective use case, such as ODM, MDM (Meter Data Management), or DCI (Digital Communication Interface). These components can include both software and hardware elements [7]. However, regardless of the selected use case, the ODM is included in all scenarios and will therefore be examined in more detail below. The main components of the ODM include the MQTT broker, the forecast model, a network data hub, and the envelope module.

The forecasting model in the ODM was a dynamic approach with a rolling window. In this regard, a Long Short-Term Memory (LSTM), which is a type of Recurrent Neural Network (RNN), with a hyperparameter optimizer was used to capture the model's features in their optimal state. For this model, three datasets with measured data from three different low-voltage grids with a 15-minute interval were used to train the model. To show the performance of this model, several days in different months and seasons were selected as testing data.

An LSTM model, with two hidden and one output layers, was used, where the first hidden and the second layer contained 100 neurons each. The ReLu Activation function and the Adam optimization algorithm were used for this model [6]. To avoid unnecessary training iterations, an early stopping technique to determine the optimal number of training iterations was implemented in this model. To select the most optimal features, a hyperparameter optimizer named RandomizedSearchCV was employed in this study. The detailed description of LSTM and other models used is available in our latest article [6].

RESULTS

First, ODM is presented, which plays a central role in the field test. It integrates essential functionalities for implementing a grid-friendly and on-demand charging infrastructure. These include an MQTT broker for communication control, a forecast model for residual load forecasting, a grid data hub for processing and providing grid-relevant information, and an envelope module for calculating dynamic envelopes. The ODM thus



forms the basis for controlling the charging infrastructure in the various use cases. Data measured and generated during the tests are recorded and visualized to allow evaluation of the introduced methods.

Fig. 49: Actual vs. Forecasted results of cumulative load profile

As the field test is currently still under development and no results on functionality, live measurements, or comparisons with forecasts are available yet, only preliminary results for the forecast model can be presented here. This was initially validated with synthetic data sets and demonstrated robust performance. This model was tested on different household levels as well as cumulative load profiles. As can be seen in Figure 1, the model was promising in predicting the pattern, and more specifically, the peaks. The evaluation metrics were measured on different levels as well: on-peak, off-peak, and the whole period. For this study, on-peak results showed better MAPE and MAE, showing the robustness of the model in catching the peaks. The last week of the year was chosen as it is among the most challenging weeks to forecast.

CONCLUSION & OUTLOOK

In conclusion, the field test will initially focus on setting up and ensuring the functionality of ODM, which serves as a central element for bringing together forecasts, dynamic envelopes, and grid and communication-related data. ODM provides the information required to control the charging points, with the specific implementation and forwarding varying depending on the respective use case. In this context, different communication and control paths are being implemented, tested, and validated in terms of reliability, robustness, and security. The aim is to demonstrate that grid-friendly and on-demand control of charging processes is possible in practice through the combined use of forecasts and dynamic envelopes.

ACKNOWLEDGMENT

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REFERENCES

[1] E.F. Bødal, V. Lakshmanan, I.B. Sperstad, M.Z. Degefa, M. Hanot, H. Ergun, M. Rossi, Demand flexibility modelling for long term optimal distribution grid planning, IET Generation, Transmission and Distribution 16 (2022) 5002–5014. https://doi.org/10.1049/gtd2.12651.

[2] F. Gonzalez Venegas, M. Petit, Y. Perez, Active integration of electric vehicles into distribution grids: Barriers and frameworks for flexibility services, Renewable and Sustainable Energy Reviews 145 (2021) 111060. https://doi.org/10.1016/j.rser.2021.111060.

[3] S. Yeom, J. An, T. Hong, C. Koo, K. Jeong, J. Lee, Managing energy consumption and indoor environment quality using augmented reality based on the occupants’ satisfaction and characteristics, Energy Build 311 (2024) 114165. https://doi.org/10.1016/j.enbuild.2024.114165.

[4] M. Gamal, M. Elhamahmy, S. Taha, H. Elmahdy, Improving intrusion detection using LSTM-RNN to protect drones’ networks, Egyptian Informatics Journal 27 (2024) 100501. https://doi.org/10.1016/j.eij.2024.100501.

[5] M.K. Kim, Y.S. Kim, N. Fu, J. Liu, J. Wang, S. Lee, J. Srebric, Advanced techniques for electricity consumption prediction in buildings using comparative correlation analysis, data normalization, and Long Short-Term Memory (LSTM) networks: A case study of a U.S. commercial building, Energy Reports 14 (2025) 56–65. https://doi.org/10.1016/j.egyr.2025.05.074.

[6] A. Fayyazbakhsh, T. Kienberger, J. Vopava-Wrienz, Comparative Analysis of Load Profile Forecasting: LSTM, SVR, and Ensemble Approaches for Singular and Cumulative Load Categories, Smart Cities 8 (2025). https://doi.org/10.3390/smartcities8020065.

[7] J. Vopava Wrienz, J. Fabini, M. Peyreder, R. Braunstein, T. Kienberger, Grid-friendly charging in residential areas: Innovative operating concepts and flexibility utilization for a future-oriented charging infrastructure, in: ETG-Fb. 176: ETG Kongress 2025, ETG-Fb. 176: ETG Kongress 2025, Kassel, Germany, 2025. https://doi.org/https://www.vde-verlag.de/proceedings-en/456494038.html.

CONFERENCE TOPIC

1.05. Digitalization for Smart, Resilient Energy Systems

ESTIMATING REAL-TIME OCCUPANCY IN MULTI-ZONE OFFICES: A COMPARISON BETWEEN CONVENTIONAL TECHNIQUES AND DEEP LEARNING METHODS

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SUMMARY

It is well known that a proper estimation of the real-time occupancy in offices is key for efficient control of the technical systems as well as for security aspects. This work presents an in-depth comparison between two contrasting methods for real-time occupancy estimation in multi-zone offices: from conventional techniques, such as the physical CO_2 mass balance, to more cutting-edge techniques based on Deep Learning (DL) methods. The aim is to compare the applicability and accuracy of both methods for estimating real-time occupancy based on non-intrusive sensors measurements. The comparability is performed both from quantitative, based on a wide range of error indicators, and qualitative point of views. The results indicate that both methods estimate real-time occupancy with remarkable accuracy, although the DL method offers slightly better results. Nevertheless, the qualitative analysis can provide additional insights when deciding whether to use one method or the other.
Keywords: occupancy estimation; physical CO_2 mass balance; hybrid Deep Learning; multi-zone office building.

MATERIALS AND METHODS

The layout of the office analysed, and the location of the sensors used for the study are indicated in Figure 1. It consists of a multi-zone office, composed of one open-plan area of 400.4 m^2 and three closed workspaces of less than 25 m^2. The office contains 44 fixed workstations (indicated in green dots) as well as occasional workstations, such as meeting rooms, with a variable number of occupants (indicated violet dots). Regarding the measurements, Sensors 1 to 4 measure temperature (T), relative humidity (RH) and CO_2 concentration from the indoor and outdoor. The mechanical ventilation system measures the ventilation rates of the supply and exhaust air streams, as well as the T of the supply air stream. In addition, the electricity consumption is measured using a wattmeter. Figure 1 also indicates, in red, the eleven vision-based devices used to measure the real number of occupants, which were strategically placed throughout to cover all zones with the presence of people, in fixed workstations, occasional workstations and transit areas. The real occupancy, as well as the other variables, were measured for 25 consecutive days, including weekdays, weekends, and holidays. The aim of this work is to compare the real occupancy recorded by the vision-based devices with the estimated occupancy obtained with the physical CO_2 mass balance and the DL method, which use measurements of non-intrusive variables.
Both methods will be explained in detail in the manuscript but, in short, the physical CO_2 mass balance method consists of applying a mass balance on CO_2 species, using the multi-zone office as the control volume. This mass balance needs to account for different properties of the inlet and outlet air streams, specifically, the indoor and outdoor T, RH and CO_2 concentrations, as well as the measurements of the mechanical ventilation system. On the contrary, the objective of the DL method is to determine the smallest subset of non-invasive devices that ensures the most accurate occupancy estimation with the lowest computational cost. To this end, it is used a hyperparameter optimization using the Non-dominated Sorting Genetic Algorithm II (NSGA-II), and a DL

architecture that includes long short-term memory (LSTM) networks and multilayer perceptrons (MLPs), so as to capture the temporal dependencies and contextual relationships inherent in occupancy behaviours.

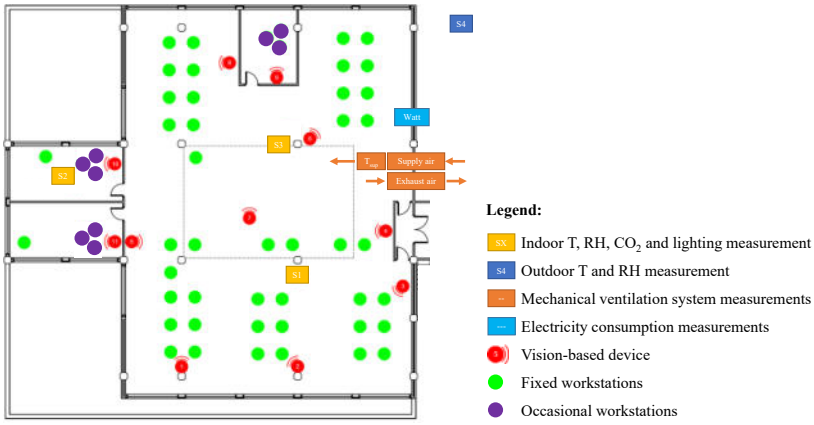


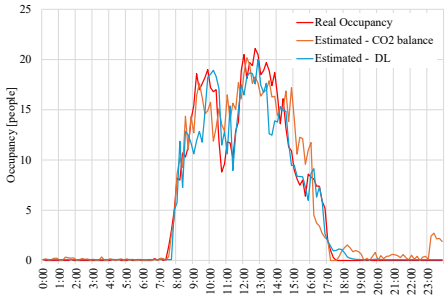
Fig. 1: Layout of the office building analysed, and location of the sensors used.

RESULTS AND DISCUSSION

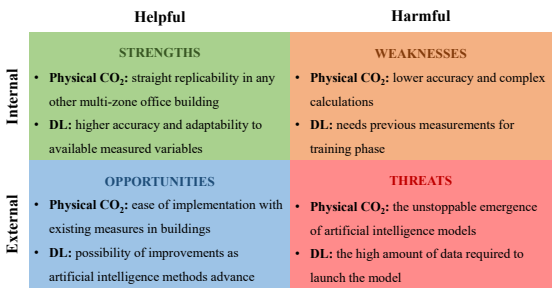
In this abstract it is only presented the results of two error indicators, namely, the Root Mean Square Error (RMSE) and the normalized Mean Bias Error (nMBE), yet in the manuscript the results of a wider set of error indicators will be explained. The results presented here correspond to the average errors of the period analysed (25 days) obtained with the best model in each case. As depicted from Figure 2(a), both methods present a similar RMSE. Considering a maximum occupancy of 33 people during the analysed period, this error represents less than 10%. Regarding the nMBE, the results obtained with the DL method outperform the ones obtained with the physical CO_2 mass balance, yet both methods tend to overestimate the real occupancy. In addition to the error indicators, a graphical comparison of the occupancy prediction obtained with both methods in a specific day is shown in Figure 2(b). It can be seen that both methods follow noteworthily the shape of the real occupancy curve: they are even capable of estimating sudden changes due to abrupt variations in the actual flow of workers.

	RMSE [people]	nMBE [%]
Physical CO_2 mass balance	2.93	+ 1.66
Deep Learning	2.32	+ 0.50

(a) error indicators



(b) graphical representation



(c) SWOT analysis

Fig. 2: results of the quantitative and qualitative analysis between the physical CO_2 mass balance and the DL methods.

As explained before, this works not only compares both occupancy estimation methods from a quantitative point of view, but also from a qualitative point of view. Figure 2(c) shows the Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis of the applicability of the physical CO_2 mass balance and DL methods. As can be seen, the main advantage of the physical CO_2 mass balance is that it can be replicated to any other office, unlike the DL method, which requires prior measurements in each building to perform the training phase. As for the DL method, its advantages lie primarily in its greater accuracy and the fact that it does not require potentially complex measurements, such as those of air flow of the ventilation system. This study contributes to making decisions based on quantitative and qualitative parameters when deciding which method to use for real-time occupancy estimation.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: **1.05. Digitalization for Smart, Resilient Energy Systems**

EQUITABLE FINANCING AND ORGANIZATIONAL MODELS FOR RENEWABLE HEATING & COOLING IN URBAN NEIGHBORHOODS

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ABSTRACT

SUMMARY

The question of which financing and organizational models are most suitable for renewable heating and cooling networks in existing (sub-)urban areas, depending on the prevailing framework conditions, is crucial to decarbonizing heating and cooling in the existing building stock. To answer this, we conduct a comparative analysis of real implementation cases and systematically assess the supporting and hindering factors across four dimensions: legal, financial, social, and organizational. A typology of project settings is then developed and linked with appropriate models for financing and implementation. Particular attention is paid to the role of municipalities, utilities, private energy service companies, and citizen energy communities, as well social inclusion and equitable cost distribution concerns. A process based decision tree is developed based on the preceding multi-dimensional research, targeting stakeholders seeking to introduce renewable heating and cooling networks in their communities.

INTRODUCTION

Decarbonizing heating and cooling in the existing building stock, especially in dense (sub-)urban areas, poses major challenges. The sector is among the largest contributors to energy consumption and carbon emissions in Europe, making it a critical field for achieving climate neutrality. Where district heating grids are not ready or expected to expand and where individual solutions are limited by space or economic and financial constraints, neighborhood-scale heating and cooling networks can provide a viable pathway. However, despite the availability of technical solutions, many projects fail to advance, not due to technical or economic limitations, but because of legal, financial, and organizational barriers.

OBJECTIVES AND METHODOLOGY

The paper addresses the central research question: *Which financing and organizational models are most suitable for renewable heating and cooling grids in existing (sub-)urban areas, depending on the prevailing legal, financial, organizational, and social framework conditions*? The objective is not only to provide a comparative academic assessment, but also to create a practical decision tool that can support stakeholders in choosing appropriate implementation pathways under specific local conditions.

The research design follows a multi-step approach. While the empirical focus lies on Austria, the methodology is designed to generate insights that are transferable to other European contexts. In the first step, a technical-economic and contextual background is established. This includes a brief overview of potential technological options such as low temperature or anergy (cold water) grids.

The second step consists of the comparative analysis of a number of case studies, complemented by literature review and expert interviews. The focus of this analysis is to identify supporting and hindering factors across four critical dimensions: legal, financial, organizational, and social. These dimensions are investigated systematically to capture the complexity of real-world implementation contexts.

In the third step, the results of the case study analysis are synthesized into a typology of project contexts. This typology differentiates, for example, between urban and suburban settings, types of initiating

actors, and patterns of stakeholder involvement. The typology serves as the foundation for linking contextual conditions with suitable organizational and financing models.

EXPECTED RESULTS AND DISCUSSION

The research is expected to yield several concrete outputs. First, a set of organizational models will be developed, illustrating how responsibilities for planning, implementation, operating, and governing neighborhood-scale heating and cooling networks can be distributed among key stakeholders under different conditions.

Secondly, a range of financing models will be analyzed, including approaches to cost recovery, refinancing structures, and cash-flow management. Particular attention will be paid to the fairness of cost distribution among different stakeholder groups, as questions of equity and affordability are central to the social acceptance of renewable energy systems.

Building on these insights, the study will present a decision framework that links different project typologies with suitable implementation models. This framework will take the form of a decision tree, designed to illustrate model suitability under specific legal, financial, organizational, and social circumstances. The aim is to make complex findings accessible in a way that can directly support stakeholders in decision-making processes.

The discussion will draw out key insights for practitioners and policymakers. It will emphasize the importance of context-sensitive solutions and of mechanisms that ensure equitable participation and cost distribution, thereby contributing to a just and inclusive energy transition. Finally, the transferability of results to other European contexts will be considered, outlining the extent to which lessons learnt in Austria can inform similar initiatives in neighboring countries.

CONFERENCE TOPIC

2.01. Financing and Business Models

2.03. Just and inclusive mechanism for the energy transition

2.06. Policy Frameworks and Support Mechanisms for Renewable Heating and Cooling

OPERATIONAL OPTIMIZATION OF PV-ASSISTED HEAT PUMP SYSTEMS USING REINFORCEMENT LEARNING

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SUMMARY

Heat pumps are increasingly integrated with PV systems to supply domestic hot water and space heating. End user purchase prices for electricity are typically significantly higher than feed-in tariffs for PV energy. From a financial perspective, it therefore makes sense to increase the self-consumption of local PV electricity and reduce the amount of energy drawn from the grid. One approach is to overheat the thermal energy storage when the heat pump can be operated with PV energy. However, with increasing temperature, heat losses increase and the heat pump's COP decreases, making excessive overheating uneconomical. The optimal degree varies with time and depends on various factors, such as heat demand, storage capacity and the purchase-to-feed-in price ratio. Using detailed system simulations, we investigate the application of a self-adaptive reinforcement learning agent than can dynamically determine the optimal degree of overheating. The agent continuously evaluates environmental and operational inputs to make informed control decisions, enhancing cost-effectiveness.
Keywords: Heat pump, photovoltaics, reinforcement learning

SYSTEM UNDER CONSIDERATION

The heating system that is used for the analyses in this study consists of an air-source heat pump, a water thermal energy storage tank, and a PV system with 8.19 kWp as the main parts, as shown in Figure 1. The air-source HP is connected to the storage, which is a combined tank (combi-store) for domestic hot water preparation and space heating. Using three-way-valves, the heat pump can charge either the upper zone of the tank, which is used for hot water preparation, via the two connections on the top or the space heating zone via the lower connections. The storage tank is connected in parallel to the heat pump and the space heating system. Hot water is prepared via a freshwater station (external plate heat exchanger) to a tapping temperature of 45 °C. The system is simulated in TRNSYS using detailed models for the heat pump, the storage tank, and the PV system. Simulations were performed using a constant time step of one minute. The model provides a test environment for training and evaluating a reinforcement learning agent.

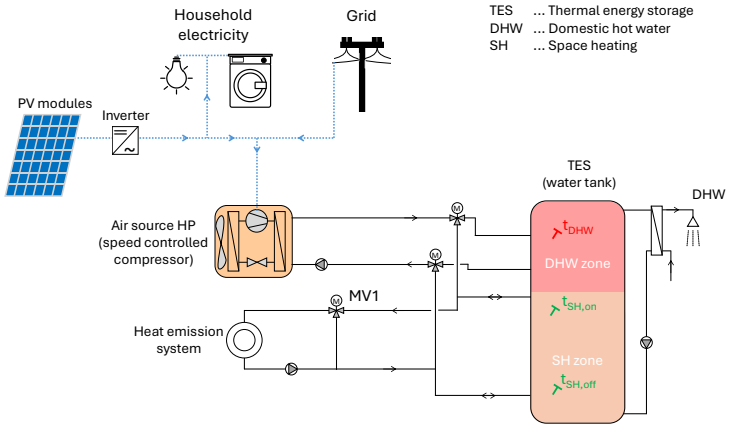


Fig. 1: System layout of the considered PV-coupled heat pump system

REINFORCEMENT LEARNING

Reinforcement Learning (RL) is a branch of machine learning focused on sequential decision-making, where agents learn through trial and error, receiving feedback in the form of rewards or penalties. In our study, the RL agent monitors variables such as buffer tank temperatures, electricity use, PV surplus, forecasts for heating demand, PV production, weather, and electricity tariffs. Based on this, it makes hourly decisions on overheating the space heating zone (0-40 K) and the hot water zone (0-15 K) in the storage tank, to shift demand to more cost-effective periods. The objective is to minimize net electricity cost, with the reward defined as the negative Net Cost of Electricity (NCOE).

In many RL-based HVAC studies (e.g., Yuan et al., 2021; Misbaudeen et al., 2024), agents directly control temperature setpoints, creating trade-offs between cost and comfort. Our setup avoids this by letting a conventional system guarantee baseline heating within comfort bounds, while the RL agent can only issue overheating commands within a safe range. This ensures its role is purely economic - shifting energy use to cheaper tariff periods or higher PV surplus - while comfort violations are structurally excluded. We used Proximal Policy Optimization (PPO) as our RL algorithm for its stability and suitability for continuous state and action spaces, utilizing Stable-Baselines3 (https://stable-baselines3.readthedocs.io) for implementation. To evaluate our approach, we conducted experiments with various buffer sizes and fixed electricity pricing as well as time-varying tariffs. **Figure 2** presents the agent's behavior during a representative test run under fixed tariffs, highlighting how it learns to manage overheating actions to minimize operational costs strategically.

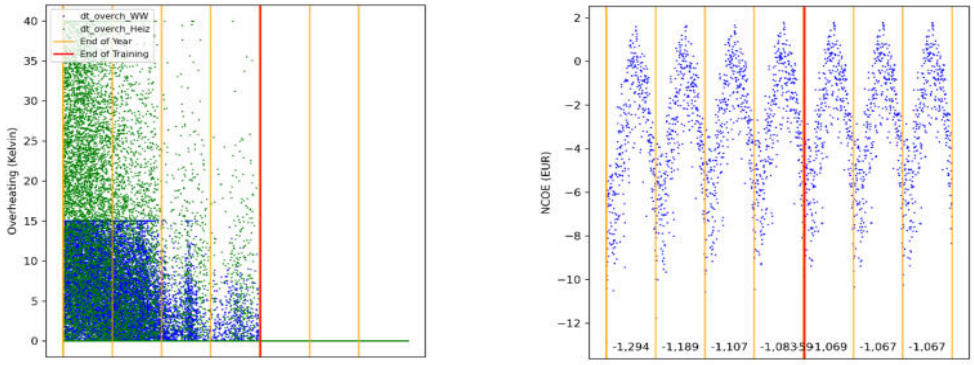


Fig. 2: Agent behaviour and cost performance during RL. *Left*: Overheating actions for hot water (blue) and heating water (green) over time, the red vertical line marks the end of the training phase. *Right:* Net cost of electricity (NCOE) across evaluation episodes. The plots illustrate how the agent's policy evolves and stabilizes toward cost-efficient operation.

ACKNOWLEDGEMENT

The research described in this paper has been carried out within the FFG AI for Green program as part of the project FO999899931 GreenHeat – The next generation of AI-based services for heat pumps funded by the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK).

REFERENCES

Yuan, X., Pan, Y., Yang, J. *et al.* (2021) Study on the application of reinforcement learning in the operation optimization of HVAC system. *Build. Simul.***14**, 75–87. https://doi.org/10.1007/s12273-020-0602-9

Misbaudeen A., Hammed O., Anis R., et al. (2024), Deep reinforcement learning for PID parameter tuning in greenhouse HVAC system energy Optimization: A TRNSYS-Python cosimulation approach, Expert Systems with Applications, Volume 252, Part A, 124126, ISSN 0957-4174, https://doi.org/10.1016/j.eswa.2024.124126

CONFERENCE TOPIC

1.05. Digitalization for Smart, Resilient Energy Systems
2.02. IT Solutions and Artificial Intelligence

DESIGNING MULTILAYERED PHOTOANODES FOR THE CO-VALORIZATION OF CO_2 AND GLYCEROL

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SUMMARY

The electrochemical conversion of CO_2 enables the production of value-added chemicals such as formate ($HCOO^-$). However, its efficiency is limited by the high energy consumption (EC) of the oxygen evolution reaction (OER) and the low economic value of the O_2 byproduct. Photoelectrochemical (PEC) systems driven by photoanodes emerge as a promising strategy to improve the energy efficiency (EE) of conventional electrochemical pathways. In this work, multilayer $CaTiO_3/WO_3/BiVO_4$ photoanodes, decorated with Ni nanoparticles synthesized via chemical reduction, are developed for coupling glycerol oxidation reaction (GOR) with CO_2 reduction to formate. The photoelectrodes are fabricated and then tested in a filter-press reactor under visible light, analyzing the effect of current density, anolyte flow rate, glycerol concentration and light intensity. This approach contributes to improve full energy efficiency (FEE) values in PEC systems, promoting sustainable CO_2 and glycerol co-valorization.

Keywords: Photoelectrocatalysis, Ni-based photoanodes, glycerol oxidation, CO_2 reduction, formate.

INTRODUCTION

The valorization of CO_2 into value-added products, such as $HCOO^-$, represents a promising alternative to tackle climate change [1]. However, the OER at the anode accounts for 80–90% of the total EC, while producing O_2 as a low-value byproduct [2]. To overcome these barriers, PEC systems with multilayer photoanodes emerge as an efficient solution, as they can harness solar energy and reduce the required external potential [3]. In our previous works, optimized loadings of 1 mg cm^{-2} $CaTiO_3$ and 3 mg cm^{-2} $BiVO_4$, with $BiVO_4$ as the top layer, led to 79.1% FE and 7.6% solar-to-fuel efficiency towards formate [4]. Then, tailored $BiVO_4/WO_3$ multilayers with an optimal 80:20 ratio improved charge transfer and reduced recombination [3]. More recently, Ni incorporation into $CaTiO_3/WO_3/BiVO_4$ photoanodes for OER allowed the operation at relevant current densities (100 mA cm^{-2}) with minimized external potential (-1.17 V vs. Ag/AgCl), reaching a maximum applied bias photon-to-current efficiency ABPE of 0.52% under visible light [5].
The aim of this work is to design energy-efficient Ni-based multilayered photoanodes for CO_2 and glycerol co-valorization, ensuring high performance and long-term robustness.

MATERIALS AND METHODS

Multilayer photoanodes are prepared by automated spray pyrolysis onto FTO substrates. The inks consisted of isopropanol (97 wt.%), Nafion (3 wt.%), and the catalyst, including $CaTiO_3$ (1 mg cm^{-2}), WO_3 (0.75 mg cm^{-2}), $BiVO_4$ (3 mg cm^{-2}), and Ni (0.5 mg cm^{-2}) nanoparticles synthesized by chemical reduction, while a Bi/C gas diffusion electrode (GDE) is employed as cathode [5] in a filter-press type PEC reactor. The catholyte (0.5 M KCl + 0.45 M $KHCO_3$) is supplied at 5.7 mL min^{-1} with CO_2 (200 mL min^{-1}), and the anolyte (1 M glycerol + 0.5 M $KHCO_3$) at the same flow rate under visible light irradiation (100 mW cm^{-2}).
PEC characterization includes chronopotentiometry (CP), linear sweep voltammetry (LSV), and electrochemical impedance spectroscopy (EIS) measurements at current densities of –10 and –45 mA cm^{-2}. $HCOO^-$ production in the cathode is analyzed by ion chromatography (IC), and HPLC is used to measure anodic glycerol-derived products.

RESULTS

First, back-illumination clearly enhances $HCOO^-$ production compared to dark conditions (Fig. 1a). At –10 mA cm^{-2}, $HCOO^-$ production in the cathode is minimized, whereas, at –45 mA cm^{-2}, both production and efficiencies are significantly enhanced, reaching values close to 97.3% FE and 34% EE under illumination. Moreover, these conditions also lead to an improved formation of products from GOR, with dihydroxyacetone (DHA) showing a notable concentration of ~360 mg L^{-1} together with acetate (ACET), as shown in Fig. 1b.

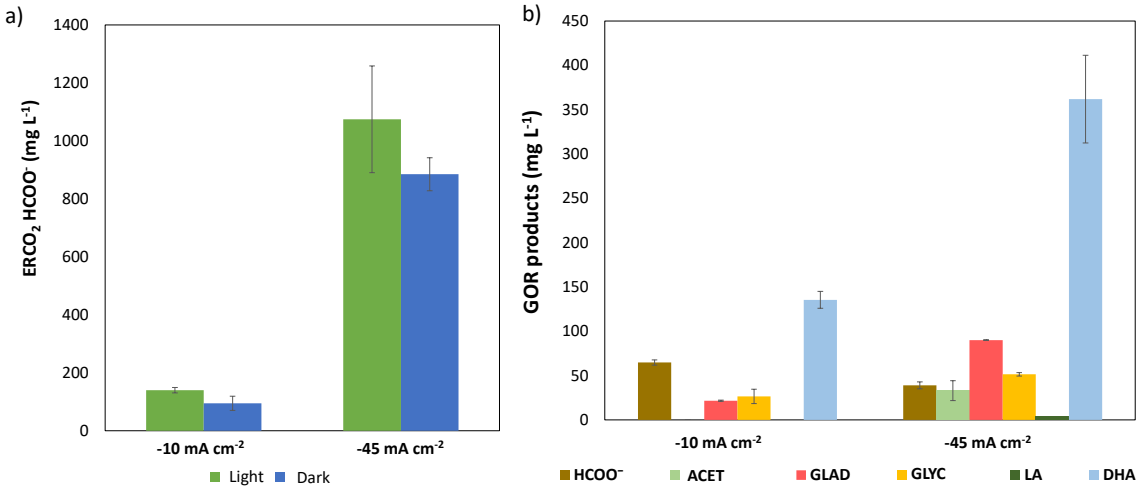


Fig. 1: a) $HCOO^-$ and b) GOR products using the Ni-based photoanodes at –10 and –45 mA cm^{-2} under visible light irradiation. GOR products include glyceraldehyde (GLAD), glycolate (GLYC), lactic acid (LA), ACET and DHA.

The work covers the effect of catalyst loading, glycerol concentration, anolyte flow, and light intensity in order to enhance FEE that maximize $HCOO^-$ production and GOR products. Stability strategies are also planned, such as coatings, surface modifications, or decoration with metals such as Co (cobalt), which is known to provide improved conductivity and stability [6].

CONCLUSIONS

Illumination reduces the required potential and enhances PEC performance, achieving 97.3% FE and 34% EE towards $HCOO^-$ at –45 mA cm^{-2}. Meanwhile, GOR selectivity clearly varies with current density, being DHA concentration ~360 mg L^{-1} at –45 mA cm^{-2}. These results highlight that optimum operation requires a compromise between CO_2 reduction and GOR performance to maximize the FEE of the process.

REFERENCES

[1] Fernández-Caso, K., et al. (2023). ACS Energy Letters, 8, 1992-2024.
[2] Balog, Á., et al. (2024). Nat. Catal., 7, 522–535.
[3] Merino-Garcia, I., et al. (2024). *Catal. Today*, 432, 114581.
[4] Abarca, J. A., et al. (2024). Catal. Today, 429, 114505.
[5] Crespo, S., et al. (2025). J. Environ. Chem. Eng., 13(5), 118854.
[6] Fang, W., et al. (2022). ACS Appl. Energy Mater., 5, 6313–6323.

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CONFERENCE TOPIC

1.14. Solar-to-X Technologies for Fuels and Chemicals

ENHANCING CIRCULARITY IN INDUSTRIAL-URBAN SYMBIOSIS THROUGH TECHNOLOGY INTEGRATION

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SUMMARY

Industrial-urban symbioses (IUS) offer a promising pathway to increase resource efficiency, utilise industrial waste heat, and strengthen local value creation. This paper presents an integration framework that combines participatory scenario development, a structured technology catalogue, and a multidimensional evaluation system embedded in an ESG Cockpit. The method was applied to a model region around the wastewater treatment plant in Gleisdorf, Austria, where three scenarios representing different levels of technology integration were analysed. The results demonstrate that relevant changes can be made visible across all evaluation dimensions - technical, ecological, economic, and social. The framework thus provides systematic decision support for advancing IUS and highlights the value of a systems thinking approach for sustainable energy and resource transitions.
Keywords: industrial-urban symbiosis, integration framework, circular economy, Systems Thinking, Gleisdorf

INTRODUCTION

The growing scarcity of resources and energy is one of the key challenges of the 21st century, as global consumption has multiplied while only a small share remains in closed cycles. At the same time, demand for clean and affordable energy continues to rise, while fossil dependencies and greenhouse gas emissions increasingly exceed planetary boundaries (UNEP, 2024; CEF, 2024). The European Union and Austria address these developments through strategies such as the European Green Deal and national circular economy policies, aiming at resource efficiency, renewable integration, and climate neutrality by 2050.

A particularly promising approach to achieve these goals are IUS, as highlighted by Castellet-Viciano et al. (2022). By coupling material and energy flows - for example, the use of industrial waste heat for building supply or the recovery of valuable materials from wastewater - synergies can be created, cycles closed, and local value creation strengthened. International examples such as the symbiosis in Kalundborg (DK) illustrate the feasibility and potential of such concepts. However, while Social and Governance dimensions are in principle promoted through ESG assessment logics such as the CSRD framework, a truly systematic approach is still missing on how technologies can be integrated into IUS and what impacts this may have on energy and resource systems striving for ethical policies and targets (Paulesich et al., 2023).

METHOD

The developed integration framework combines data-based modelling, technology-oriented information processing, and participatory decision-making. It consists of three closely interconnected modules:

1. Stakeholder-involvement and scenario development

Industrial-urban symbioses can only be realized through the active participation of relevant actors. Therefore, the method employs the planning and participation tool *Urban Menus* (Bußwald et al., 2024), which enables the

integration of diverse stakeholder perspectives into scenario development. This allows joint target visions to be created and potential synergies to be identified at an early stage. The spatial and resource-related database is complemented by GIS analyses and data collection from industrial actors.

2. Technology catalogue and modelling layer

At the core of the method lies a structured technology catalogue, in which key technologies are documented across the dimensions of energy, water, and materials. Standardized factsheets provide technical, economic, and ecological parameters, input/output flows, and basic application requirements. This database is transferred into an object-oriented model structure based on a hybrid input-output approach. In this way, urban and industrial actors, resource interfaces, and technologies can be linked in a technology-open manner and different scenarios simulated.

3. Evaluation system and ESG-Cockpit

For the comparative analysis of scenarios, a multidimensional indicator system has been developed that covers technical, ecological, economic, and social impact dimensions. The selection is aligned with the EU Circular Economy Monitoring Framework and extended by energy- and resource-related metrics. Through the ESG Cockpit, indicators are calculated and analysed under different weightings, with the social dimension also reflecting socio-cultural aspects such as user diversity and acceptance. This ensures that the evaluation highlights societal benefits alongside environmental, economic, and technical performance.

The framework delivers scenario comparisons along the four evaluation dimensions and serves as decision support for the selection of appropriate technology pathways and cooperation models. The modular and data-driven structure of the framework enables robust insights even under limited data availability and allows iterative application across different urban and industrial contexts, from initial screening analyses to detailed feasibility studies.

APPLICATION

The method was tested in a model region centred around the wastewater treatment plant (WWTP) in Gleisdorf. Three scenarios were examined, representing different levels of technology integration: a baseline scenario with WWTP, photovoltaic systems and a heat pump; a moderate integration scenario including additional circular technologies; and an innovation scenario with extended PV deployment and an electrolyser.

The comparison reveals significant effects across all evaluation dimensions. From a technical perspective, the electrical self-sufficiency increases from 1.44 % in the baseline to over 41.21 % in the innovation scenario, while the circular output ratio rises to 38.65 %. In the ecological dimension, annual greenhouse gas savings from substitution reach up to 1,708 t CO_2eq. Economically, annual savings from on-site energy generation grow to € 1,093,900 in the innovation scenario. Preliminary social assessments indicate additional employment effects and broader diversity of use.

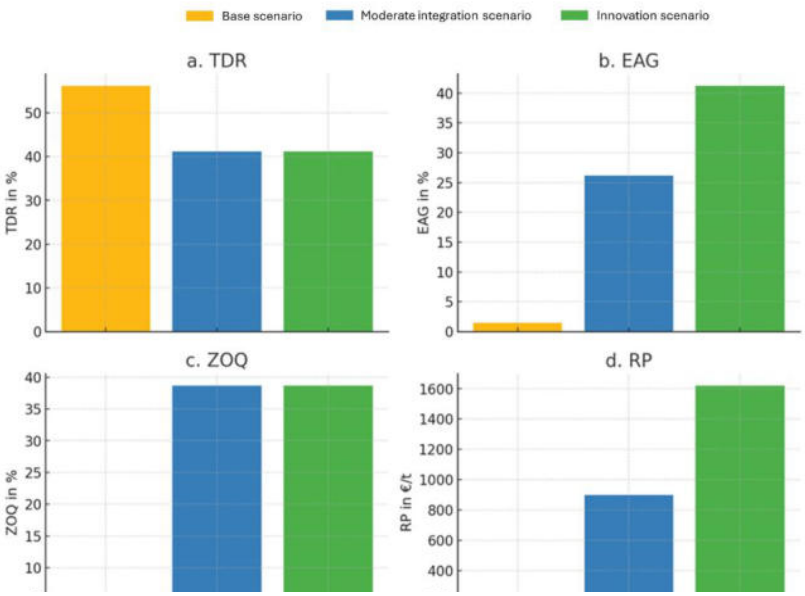


FIGURE 1: COMPARISON OF THE TECHNICAL EVALUATION DIMENSION BETWEEN THE SCENARIOS USING THE KPIS THERMAL COVERAGE RATE (A), ELECTRICAL SELF-SUFFICIENCY (B), CIRCULAR OUTPUT RATIO (C), AND RESOURCE PRODUCTIVITY (D).

The case study demonstrates that the integration of further technologies not

only generates ecological benefits but also creates substantial economic and social value.

ACKNOWLEGEMENTS

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REFERENCES

Busswald P., Annatour A., Besse V., Kraml B., Niederl F.: Nachhaltigkeit messbar machen, In: Paulesich, R.; Feser, D.; Strohmaier, M. (2023) Ethisch ökologische Unternehmenspolitik; Springer Gabler Management; Heidelberg

Bußwald, P., Spinadel, L. P., Besse, V., Cojocariu, C., Kampl, T., Kraml, B., Niederl, F., Pedraza, C., Severin, B., Taşpınar, Ö., & Dan, S. A. (2024). URBAN MENUS: Enhancing decision-making in early-stage projects. 8770–8779. https://doi.org/10.21125/iceri.2024.2201

Castellet-Viciano, L., Hernández-Chover, V., Bellver-Domingo, Á., & Hernández-Sancho, F. (2022). Industrial Symbiosis: A Mechanism to Guarantee the Implementation of Circular Economy Practices. Sustainability, 14(23), 15872. https://doi.org/10.3390/su142315872

Circle Economy Foundation. (2024, Januar 31). Circularity Gap Report 2024.

UNEP. (2024). Bend the trend: Pathways to a liveable planet as resource use spikes. International Resource Panel.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

1.10. Industrial and Urban Symbiosis
1.03. Circular Economy Strategies for the Energy Transition

EVALUATING LOCATIONS FOR SEASONAL THERMAL ENERGY STORAGES

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SUMMARY

Seasonal thermal energy storages (sTES) can support district heating decarbonisation, but their design is strongly affected by groundwater flow, which increases heat losses and increases regulatory requirements. Groundwater can increase sTES heat losses by 30-70%, making site selection essential. This study analyses the integration of a sTES >0.5 Mm³ in Vienna, comparing a shallow pit and a deep underground tank. Key technical and economic factors include groundwater, pipe insulation, distance, grid connection, charging/discharging time, and investment costs. Surplus heat availability and supply–return temperature differences are critical for transport-line design and costs.

INTRODUCTION

The integration of sTES in district heating (DH) systems, alongside renewable heat sources, is a promising step toward decarbonising the DH sector. Denmark has already implemented several pit thermal energy storages (PTES), demonstrating their efficiency and low cost, while other European countries, such as Austria, are heading towards building the first large-scale sTES. The design of large-scale sTES is strongly influenced by groundwater, which can reduce thermal performance and trigger regulatory constraints on groundwater temperature rise. Mitigation measures, such as cut-off walls or thermal insulation, have been tested in the gigaTES[1] and ScaleUp[2] projects, proving effective. However, groundwater remains a technical, economic, and legal challenge that can heavily affect design and even project feasibility. Therefore, groundwater presence and levels must be assessed at an early stage. Recognising these challenges, we determine the distance between the DH system and sTES location for which a sTES located in an area without groundwater flow can compete with a nearby sTES located in an unfavorable area with groundwater flow. We look at different scenarios and investigate different design and operation options for efficient heat transport between the sTES and the DH network. Aiming to assist on the search for a sTES location by constraining the search-area to feasible locations and on the other side, investigate design and operation strategies that expand this constrained area.

METHODOLOGY

This study focuses on the Viennese DH system and future scenarios of sTES larger than 0.5 Mm^3. Two contrasting designs are considered: a shallow pit (typical of Danish PTES) and a deep underground Tank TES with vertical walls (as in the 40,000 m³ ScaleUp pilot [2]). The DH system is assumed to act as both source and sink for the stored heat, with only limited local post-heating at the sTES site. An initial set of scenarios is screened through rough calculations to identify the most relevant cases for detailed analysis. The evaluation includes technical factors such as groundwater presence, pipe insulation, distance to the DH system, grid connection (primary/secondary), charging/discharging duration, and storage size. The economic assessment considers investment costs, component lifetimes, and operation and maintenance expenses.

RESULTS

Surplus heat availability is expected to be a key factor, as it defines the required transport-line capacity. For instance, charging a 700,000 m³ (~40 GWh) TES in 30 days requires about 56 MW_{th} capacity, while doubling the charging time halves this demand, allowing smaller pipe diameters and lower costs. Transport capacity also depends on the supply–return temperature difference, making return temperature reduction particularly important. Potential solutions include cascade heating, where the primary grid return supplies secondary grids[13] via heat pumps, or using absorption heat exchangers (AHE) [3].

Locating an sTES farther from the DH system is only justified if investment savings or efficiency gains outweigh the added transport costs. One potential benefit of relocation is the reduction of heat losses by avoiding groundwater. In this regard, previous studies [1,4,5,6] highlight the impact of groundwater on TES performance. [4] and [5] considers a single charge-discharge cycle and estimate an increase of the overall heat losses due to groundwater flow of 403 MWh/a (56%) and 290 MWh/a (48%) respectively. [4] studies a 75,000 m^3 TES operated between 90°C to 15°C while [5] considers a 100,000 m^3 TES operated at 90°C to 60°C. [5] also emphasized that losses can be reduced through mitigation measures, though only at additional cost. For larger systems, similar effects are observed. Results for a 2 Mm^3 underground Tank TES are presented in [1,6]. Overall heat losses with groundwater (assuming a flow velocity of $2.5e^{-6}$ m/s) are 9.3 GWh/a, about 2.8 GWh/a (30%) higher than the case without ground water. A similar trend is observed for the 0.5 Mm^3 Tank TES, the increase of heat losses due to groundwater flow is roughly estimated in 1.8-1.9 GWh/a (~70%). Based on the above estimates, a preliminary assessment illustrates the relevance of the topic. Consider a transport line with a DN 250 pipe, sufficient for ~28 MW_{th}. Assuming a temperature difference of 60 K, the flow rate would be about 410 m³/h, corresponding to a design velocity of ~2.1 m/s and a pressure drop of ~130 Pa/m. With high insulation class 3, an average operating temperature of 80°C (e.g. 110°C supply and 50°C return), and a ground temperature of 10°C, the overall heat loss from supply and return lines is about 40 W/m. If the transport line operates for four months per year (~2880 h, with two months for charging and two for discharging), this corresponds to ~115 kWh/m. From this, a threshold distance of ~15 km can be estimated, equivalent to ~1.7 GWh of heat losses. This value is a rough estimate based on specific assumptions and design choices, and could be improved through optimization measures such as lowering the return temperature. However, in practice, the feasible distance may be shorter once additional investment costs for the transport line are considered, though a longer distance could still be justified in a more optimized design.

REFERENCES

[1] Van Helden, W., et al. (2021) Giga-scale thermal energy storage for renewable districts. Publishable Final Report. https://www.gigates.at/index.php/en/publications/reports

[2] Wien Energie. ScaleUp. Available at URL: https://www.wienenergie.at/scaleup/ (Accessed: 05.09.2025)

[3] Zotter, G. et al. (2023) An energetical, exergetical and experimental analysis of an absorption heat exchanger used as transfer substation in an already existing district heating grid.

[4] Ioannis Sifnaios, et al. Heat losses in water pit thermal energy storage systems in the presence of groundwater. Applied Thermal Engineering. Applied Thermal Engineering,
Volume 235, 2023, 121382, ISSN 1359-4311, https://doi.org/10.1016/j.applthermaleng.2023.121382.

[5] Abdulrahman Dahash, et al. Numerical Analysis and Evaluation of Large-Scale Hot Water Tanks and Pits in District Heating Systems. 16th IBPSA int. Conference. 2019. 2-4 Sept. Rome.

[6] Abdulrahman Dahash, et al. Understanding the interaction between groundwater and large-scale underground hot-water tanks and pits, Sustainable Cities and Society, Volume 71, 2021, 102928, ISSN 2210-6707, https://doi.org/10.1016/j.scs.2021.102928.

[13] Wien Energie supplies heat to many consumers via the connected secondary district heating network (DHN). District heating (DH) substations ("Gebietsumformerstationen") transfer heat from the high temperature (primary) DH network to the "low" temperature (secondary) DHN.

CONFERENCE TOPIC

1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

SOIL INVESTIGATIONS FOR PIT THERMAL ENERGY STORAGES

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SUMMARY

The growing global energy demand has intensified the need for renewable energy sources and efficient storage solutions as Smart Energy Infrastructure. As renewable energy sources, such as wind turbines and solar parks, gain prominence, the development of large-scale thermal energy storage systems for district heating systems becomes essential, as they offer cost-effective seasonal storage. Among these, Pit Thermal Energy Storage (PTES) systems have emerged as a promising solution, with storage capacities up to 1,000,000 m³ and are most frequently built, due to the low building expenses. However, knowledge of soil mechanics under thermal influence is necessary in the planning phase to achieve optimal design. Although soil investigations are part of the regulations, the thermal influence is often neglected. To address this gap of data on soil stability, laboratory investigations have been carried out to estimate the development of soil stability as well as the heat loss of the storage during operation.
KEYWORDS: Pit Thermal Energy Storage, temperature-controlled oedometer, stiffness, numerical analysis.

INTRODUCTION

PTES systems consist of excavated pits lined with protective membranes, filled with water, and insulated with floating layers to minimize heat loss. Operating temperatures for PTES typically range between 30 to 95 °C, causing thermal diffusion into surrounding soils which significantly alter their properties, including compressibility, creep, shear strength, stiffness, thermal conductivity, and moisture content. However, standard geotechnical testing, generally conducted at natural ground temperatures (10–20 °C), inadequately represents soil behaviour under these elevated thermal and mechanical stresses, making the study of thermo-mechanical behaviour in soils both complex and essential.
This research explores the compressibility and creep behaviour of fine-grained soils using a temperature-controlled oedometer apparatus across a temperature range of 20 °C to 95 °C. Additional experiments evaluate shrinkage, moisture content, and thermal conductivity.

LABORATORY TESTING

The laboratory investigation of soils intended for Pit Thermal Energy Storage (PTES) applications shall be carried out in accordance with established international/national standards, with modifications to accommodate elevated temperature testing. The testing program addressed the physical, thermal, hydraulic, and mechanical behaviour of soils under operational temperature conditions representative of PTES systems.
The oedometer is a standard method to measure the load response of a soil sample [A. Tarantino, 2009]. For the thermal control of the sample material, a heating sleeve was added following the principle of Villar and Lloret (2004). The experimental configuration enables precise measurement of soil compressibility parameters under combined thermal and mechanical loading, with particular attention to temperature-dependent deformation

characteristics, thermal hardening/softening phenomena, pore pressure evolution under non-isothermal conditions, and small-strain stiffness variations via ultrasonic measurements.
A reference measurement of the soil at room temperature has been performed, along with a set of standard measurements to identify the soil properties. Thermal conductivity was measured on both reconstituted samples and intact samples over a wide range of moisture contents and a wide range of different soil types (clay, sand, silt and peat). The sensor used complies with the internationally recognized standard of ASTM D5334-14.

RESULTS

The thermal conductivity of our soil samples shows a maximum of ~2,5 W/mK at ~50 % and falls for higher moisture contents. At high moisture contents the thermal conductivity approaches the value of water (~1 W/mK). High moisture contents in the range of 200-300 % can occur in peat. According to literature, typical thermal conductivities are around 0.5 W/mK in dry soils and 2.0 W/mK at moisture contents of 40 %. However, both peat and dry clay or sand have low compressive strengths and therefore non-ideal geotechnical stability.

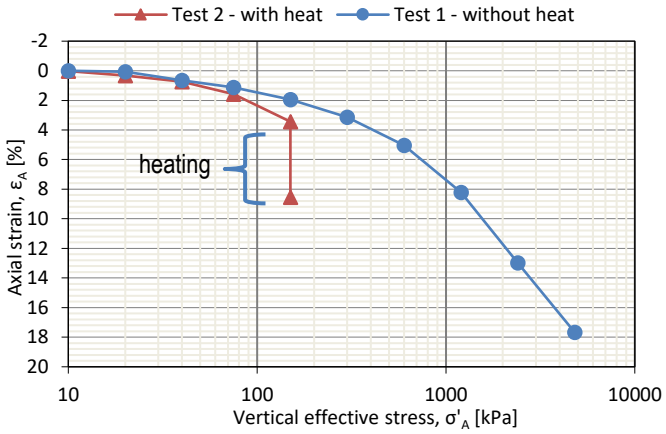


Figure 50: Effect of temperature on axial strain with effective vertical stress

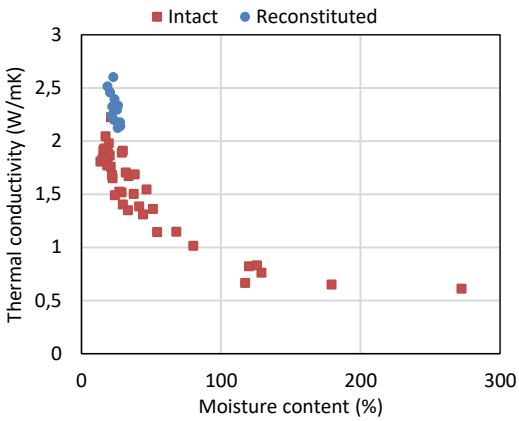


Figure 51: Thermal Conductivity of soil samples with various moisture contents

A trade-off of thermal conductivity and compressive strength shows that the best conditions for soils surrounding PTES are at 60-100% moisture: thermal conductivity is lower than the maximum, but loading tests show sufficiently high stability of most soil types in this range.

REFERENCES

Alessandro Tarantino et al., eds., (2009) Laboratory and Field Testing of Unsaturated Soils (Springer Netherlands) https://doi.org/10.1007/978-1-4020-8819-3.
M.V Villar and A Lloret, (2004) Influence of Temperature on the Hydro-Mechanical Behaviour of a Compacted Bentonite, Applied Clay Science 26, Nr. 1–4, 337–50, https://doi.org/10.1016/j.clay.2003.12.026.
David Bertermann et al., (2024) A Practicable Guideline for Predicting the Thermal Conductivity of Unconsolidated Soils, Soil Systems.
Verein Deutscher Ingenieure (2004) VDI 4640-Part 4 - Thermal Use of the Underground: Direct Use, Beuth Verlag.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
Building the Future: Smart Energy Infrastructure for the Energy Transition

ENERGY BOOSTER; A QUALIFICATION AND INFORMATION OFFENSIVE FOR INNOVATIVE BUILDING TECHNOLOGY AND RENEWABLE ENERGIES

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ABSTRACT

Recently, the energy transition seems to gain urgent and much needed momentum. Energy techniques and measures are available in large quantities reducing carbon dioxide emissions, and they are being adopted in more and more buildings. However, those working in the construction industry at site installing HVAC-systems have little opportunities to get themselves educated or informed about new developments to reduce energy use, improve comfort or to make more use of renewable energy resources. Due to a shortage of employees (resulting in a high workload), a lack of subsequent training and further education possibilities, improvements are needed.

Four organisations are in an international project called 'Energie Booster' or Energy Booster collaborating to improve subsequent training possibilities and to help employees in the sector to move upwards in and employees from other sectors to move towards to that part of the construction industry that is thriving. Two educational organisations are located in the cities Münster and Osnabrück in Germany, being the Handwerkskammer Münster and Handwerkskammer Osnabrück, and two in the cities Enschede and Hengelo in the Netherlands, namely ROC van Twente and Saxion UAS.

Table 1: Overview of the twelve foreseen courses to be developed in Energy Booster

#	English course name	German course name	Dutch course name
1	Photovoltaic panels	Photovoltaik	Fotovoltaïsche systemen
2	Heat pumps	Wärmepumpen	Warmtepompen
3	Heat networks	Wärmenetze	Warmtenetwerken
4	Climate control, ventilation, and heat recovery	Klima, Lüftung und Wärmerückgewinnung	Klimaatbeheersing, ventilatie en warmteterugwinning
5	Sector integration	Sektorkopplung	Sectorintegratie
6	Combined Heat and Power (CHP)	Kraft-Wärme-Kopplung (KWK)	WarmteKrachtKoppeling (WKK)
7	Energy management	Energie-management	Energiemanagement
8	Energy storage	Energie-speicherung	Energieopslag
9	Smart Home	Smart Home	Smart Home
10	The house as a system	Das Haus als System	Het huis als systeem
11	Customer advice	Kundenberatung	Klantenadvies
12	Green hydrogen	Grüner Wasserstoff	Groene waterstof

In 2023 these four organisations embarked on a mission to develop concise real life and online courses for those who are already working on twelve different topics (see Table 1). Within the project the courses focusing on the energy transition will not only be designed, but pilot-courses will also be provided for free, as a first test to gain

experience enabling the designing teachers involved to make improvements. Furthermore, excursions will be organised and a train-the-trainer-program is developed and provided to make sure multiple teachers are available to the German-Netherlands Interreg region.

In order to enable other regions to also develop attractive courses that can help in the energy transition and targeting those working or willing to work in the construction industry, this paper elaborates on the project organisation, the educational topics and the educational design processes. Despite initial delays (due to staffing and scheduling challenges) the project has made substantial progress, because:

- 12 courses were introduced, developed and translated;
- pilot courses were offered by all partners, with varying formats and participant numbers (e.g., Saxion's energy storage pilot course attracted 19 participants);
- an expert conference was organised with 74 participants;
- 8 excursions were provided, including among others visits to hydrogen and ventilation technology sites;
- 3 consultations were conducted with SMEs on energy optimization and funding;
- 1 of 4 Train-the-Trainer sessions was completed.

Our lessons learned in designing and providing the courses are likely to benefit other educational and knowledge institutions in disseminating energy transition knowledge and experiences to their students. Key lessons include the importance of integrating modules into existing programs to ensure uptake, and the need for flexible formats tailored to different target groups. The project partners plan to expand outreach to include policymakers and network operators, while continuing to support vocational learners. Last, but not least, we will look forward on how the project Energie Booster is going to be finalised and what might going to be done afterwards as a sequel.

ACKNOWLEDGEMENTS

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CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
2. Support Schemes for Implementation in Buildings, Industry, Districts, Cities and Regions
2.05. Marketing, dissemination and implementation strategies

NATURAL DEEP EUTECTIC SOLVENTS AND IONIC LIQUIDS AS SORPTION MEDIA IN ABSORPTION HEAT PUMPS

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SUMMARY

Alternative sorbents for absorption heat pumps are investigated to overcome problems such as crystallization and corrosion that comes with the state-of-the-art working pair H_2O/LiBr. In this project, ionic liquids and natural deep eutectic solvents were screened as sorption media with water as refrigerant. Experiment at ambient conditions showed leading candidates reaching up to 0.324 $g_{water}/g_{sorbent}$ water uptake (LiBr: 0.239 $g_{water}/g_{sorbent}$). Viscosity and density measurements proved workable behaviour for absorption heat pumps. Ambient tests for water uptake and release were underlined by the determination of the solution field. Further measurements included hydrolytic and thermal stability, glass-transition temperature, specific heat capacity, heat of solution, and corrosivity. The best working sorbents will be tested in a pilot scale absorption heat pump in the lab.

INTRODUCTION

Absorption heat pumps (AHPs) are a proven route to upgrade and valorize low- to medium temperature industrial waste heat, cutting primary energy use and emissions in sectors needing process heat of at least 80 °C. [1] The benchmark working pair is H_2O/LiBr due to the high latent heat of water and relatively benign environmental profile of this working pair. However, H_2O/LiBr operation near the concentration and temperature limits are constrained by narrow crystallization margin and by corrosion risks at high LiBr mass fractions and elevated temperatures in the generator and desorption unit.[2] Consequently, current research targets alternative sorbents that retain strong hygroscopicity while mitigating both crystallization and corrosion. In this research, particularly natural deep eutectic solvents (NADESs) and environmentally benign ionic liquids (ILs) are being investigated. Both, ILs and NADESs based working pairs are attractive because of their negligible vapor pressure and tunability of physical properties depending on chosen constituents. Recent modelling and experimental studies show that several ILs and DESs can deliver competitive absorption performance in AHPs.[3,4] The project "AbSorbEnt" undertakes a structured workflow: (i) multi-criteria screening to selct possible NADES and IL candidates; (ii) preparation of NADES; (iii) application-oriented property characterization; (iv) investigation of the solution field for water; and (v) running a demonstrator unit with the most promising solvents remaining based on the previous selection criteria. The screening prioritizes high water affinity at near-saturated humidity (~ 95% RH) at ambient pressure. To enable a comparison to the H_2O/LiBr working pair, a 54 wt.% aqueous LiBr solution was also investigated at the same conditions and environment. Measured, process-critical properties include melting point to avoid solidification within the AHP, dynamic viscosity to evaluate pumpability and

density, that is crucial for hydraulic design and equipment sizing. Complementary literature benchmarking of candidate working pairs against H_2O/LiBr provide context on feasible temperature lifts, crystallization safety margins, and in industrial waste-heat upgrading.

RESULTS

Preliminary screening under ambient conditions showed water uptakes as high as 0.324 $g_{water}/g_{sorbent}$ within 24 h at ambient temperature, pressure and 95 % RH, outperforming the LiBr reference (0.239 $g_{water}/g_{sorbent}$). Subsequent desorption experiments proved that all sorbents are capable of releasing former absorbed water in a low humidity atmosphere (16 % RH) at ambient temperature and pressure, as shown below in Fig. 12 with the working pair H_2O/LiBr containing 54wt.% LiBr (noted as LiBrW) as reference. To underline these results, the solution field for water uptake and release was determined for the most promising solvents, which were selected based on obtained physicochemical properties.

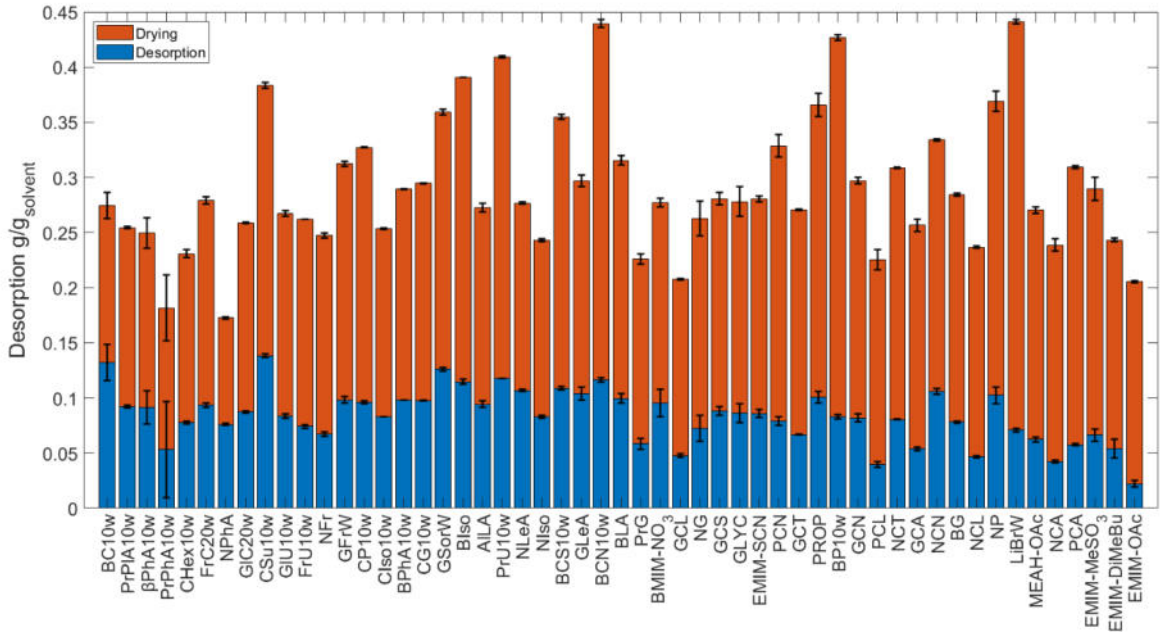


Fig. 12: Bar-chart diagram for the amount of desorption of water in a 16 % relative humidity atmosphere at ambient temperature for 24 h followed by drying in a drying chamber at 100 °C for 1 h.

Across the process-relevant temperature window, the selected sorbents exhibited densities of 1.0722 - 1.3347 g/cm³ at 10 °C and 1.0299-1.2800 g/cm³ at 80 °C, while dynamic viscosities decreased from 0.056 - 19.154 Pas at 10 °C to 0.001 – 0.073 Pas at 80 °C. To translate these material metrics into operating performance, coupled absorption-desorption experiments are being conducted between 30 and 200 °C at vapor pressures consistent with water as the refrigerant. Besides that, additional crucial properties such as the glass transition temperature, analyzation of thermal stability by thermal gravimetric analysis alongside with the determination of specific heat capacity, heat of solution, corrosivity, stability against hydrolysis and long-time stability by containing 25 wt.% water at elevated temperature is also investigated to provide a complete property set for process design and durability assessment. Finally, the most promising IL and NADES will be tested as sorption media in a pilot-scale absorption heat pump in the lab, allowing testing of the performance of alternative sorption media in a real process.

CONFERENCE TOPIC

REFERENCES

1 D. S. Ayou, W. Wu and A. Coronas, *Thermal Science and Engineering Progress*, 2025, **62**, 103679.
2 K. Wang, O. Abdelaziz, P. Kisari and E. A. Vineyard, *International Journal of Refrigeration*, 2011, **34**, 1325–1337.
3 M. Wang and C. A. Infante Ferreira, *Applied Energy*, 2017, **204**, 819–830.
4 T. Di Pietro, L. Cesari and F. Mutelet, *Energy Conversion and Management*, 2023, **293**, 117491.

AN OVERVIEW OF RENEWABLE HEATING & COOLING (RHC) TRAINING AND CAPACITY BUILDING ACTIVITIES OF THE SOLTRAIN+ PROJECT IN BOTSWANA.

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SUMMARY

The Southern African Renewable Heating and Cooling Training and Demonstration Initiative (SOLTRAIN+) project provides training and capacity building on renewable heating and cooling technologies in Southern Africa with funding from the Austrian Development Agency (ADA). This paper presents an analytical summary of the training activities undertaken between the years 2024 and 2025 under the SOLTRAIN+ project in Botswana. It communicates the total number of trainees during this period, including gender categorization to highlight SOLTRAIN+ Botswana's commitment towards gender inclusivity. The study also groups training workshops by their types which comprise of dissemination workshops, practical workshops, and specialized workshops among others. Lastly, the impacts of SOLTRAIN+ solar thermal trainings in Botswana is presented, as well as an outlook on the pathways to maximize impact and improve the overall quality of trainings in Botswana and other partner countries.

Keywords: Renewable Heating and Cooling; Solar Thermal; Training; Capacity Building

CONFERENCE TOPIC

2.05. Marketing, dissemination and implementation strategies

EXPLORATION OF SAND AS A HIGH TEMPERATURE THERMAL ENERGY STORAGE (TES) MATERIAL FOR THE GROWING RENEWABLE ENERGY MARKET IN BOTSWANA

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SUMMARY

This study presents an investigation of six (6) sand samples from various geographic locations in Botswana for their feasibility as high temperature sensible thermal energy storage materials. The main objective of the study is to thermally characterize sands by investigating their decomposition under thermal stress, the variation of their thermo-physical properties, agglomeration effects, phase transitions, and many others. The tested sand types were sampled from Kgalagadi, Ghanzi, Maun, Sowa Town, Francistown and Gaborone in Botswana. The study used a differential scanning calorimeter (DSC) for thermal energy characterization, a thermogravimetric analyzer (TGA) for thermal stability and mass loss determination, and an X-ray fluorescence (XRF) analyzer for elemental composition of the sand samples. Results from the aforementioned tests will establish the sand types that possess the appropriate thermal properties for sensible thermal energy storage. This study is still ongoing, and it is expected to yield results that are crucial in the development of thermal batteries to store renewable energy, especially solar energy, in Botswana.

Keywords: Sensible thermal energy storage; Sand; Thermal characterization

CONFERENCE TOPIC

1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage
1.07. Flexibility and Stability in Thermal and Electric Grids

TECHNO-ECONOMIC OPTIMIZATION OF HYBRID SOLAR ENERGY SYSTEMS FOR PROCESS HEAT APPLICATIONS

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SUMMARY

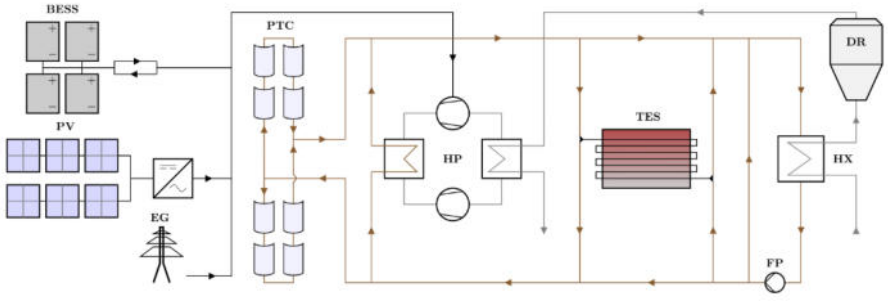
This study assesses a hybrid solar energy system for cost-effective and low-emission process heat production. The system combines photovoltaics, battery storage, parabolic troughs, a high-temperature heat pump, and thermal storage to supply a dryer with 200°C air. The study evaluates levelized cost of heat and annual operating emissions in Würzburg, Germany, and Almeria, Spain. Techno-economic optimizations in DLR's in-house tool YACOP identify Pareto-optimal component capacities and operating strategies. Results show trade-offs between investment and operational costs, and emissions. The hybrid system demonstrates competitive levelized costs and significant emission reductions compared to fossil gas burners, with Almeria achieving better performance due to higher solar irradiation.

INTRODUCTION

Solar thermal collectors, including parabolic trough collectors, can contribute significantly to the defossilization of process heat, even in regions with lower solar irradiation, such as Central Europe [1]. The integration of solar thermal collectors with high-temperature heat pumps for process heat applications can address the limitations inherent to each technology, such as variable solar irradiance and restricted heat source capacity [2]. Additionally, heat pumps can benefit from integration with low-cost photovoltaic power, as opposed to purchasing electricity from the grid [3]. Consequently, this study conducts a techno-economic assessment of a hybrid solar energy system (HSES) comprising a photovoltaic field (PV), battery energy storage system (BESS), parabolic trough field (PTC), high-temperature heat pump (HP), and concrete-based thermal energy storage (TES) to deliver cost-effective and low-emission process heat.

MATERIALS AND METHODS

The HSES supplies a dryer (DR) with air at 200 °C to meet a constant heat demand of 1.84 MW. Hot air is generated by a heat exchanger (HX), which is supplied by a thermal oil circuit with a parallel configuration of PTC and HP, and a TES in series. The HP can be powered by PV, BESS, or the electricity grid (EG). The DR outlet flow has a temperature of 80 °C and is directed to the HP as heat source. All component interconnections and the integration of DR are illustrated in Figure 1. For this investigation, we examine the levelized cost of heat



(LCOH) and annual operating emissions (AOE) at two locations, Würzburg (Germany) and Almeria (Spain), which represent different irradiation and market conditions.

Fig. 1: Schematic of the HSES and DR integration.

Given the complexity of the hybridized system, optimization methods are applied to identify Pareto-optimal component capacities and corresponding optimal operating strategies. The techno-economic optimization is performed using DLR's Yield Assessment Calculation and Optimization Program (YACOP), which enables the use of component models on different detail levels and will be introduced in more detail in the full paper.

RESULTS AND DISCUSSION

Figure 2 illustrates the Pareto-optimal LCOH over AOE at the bottom, along with the corresponding component capacities at the top, calculated for Würzburg (left) and Almeria (right). For both sites, the PV, PTC, and TES capacities increase as the AOE approaches its minimum and decrease as the LCOH approaches its minimum. This indicates that the optimization process involves a trade-off between high investment costs, increased operational expenditures, and emissions. Additionally, the higher solar irradiation available in Almeria results in a lower LCOH and significantly reduced AOE values compared with the lower irradiation available at the Würzburg site. To contextualize these findings, a fossil gas burner solution was examined to meet the specified demand, yielding an LCOH of 109 €/MWh and an AOE of 5650 t/a. Consequently, the proposed system demonstrates cost-competitive LCOH values, with AOE reductions exceeding 60% for Würzburg and 97% for Almeria. The full paper will present optimal operating strategies and provide a detailed discussion of the results.

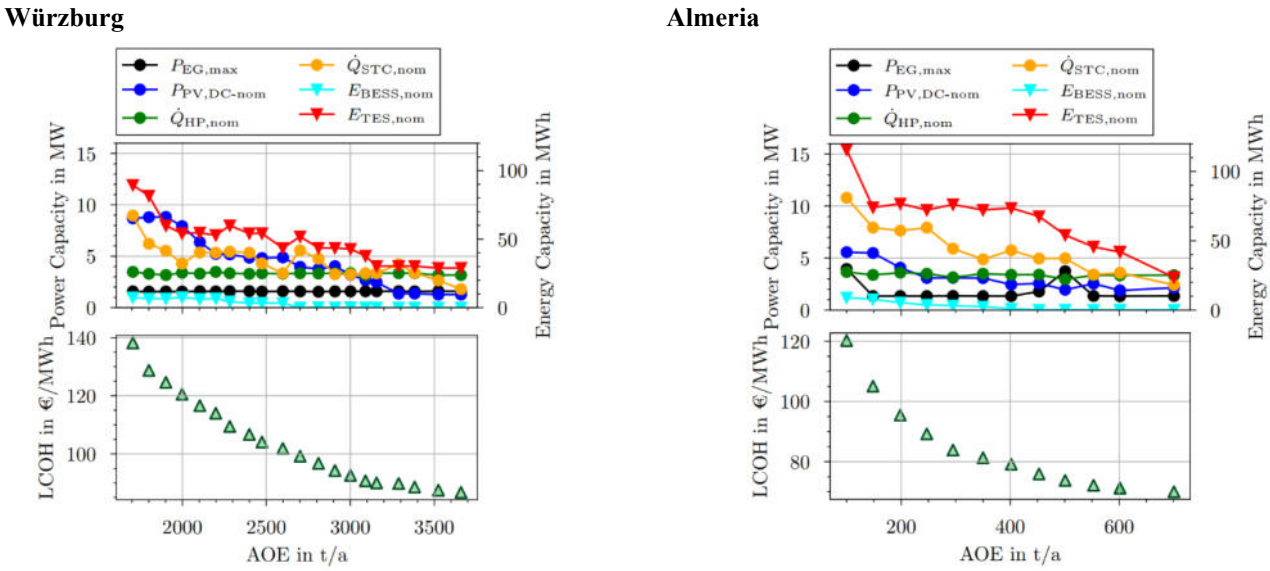


Fig. 2: Pareto-optimal LCOH over AOE and corresponding optimal design capacities.

REFERENCES

[1] D. R. Krüger, et al., (2021), Chancen für den Einsatz konzentrierender Kollektoren in Mitteleuropa, Symposium Solarthermie und innovative Wärmesysteme, pp. 1-14, url: https://elib.dlr.de/145751/.

[2] M. Jesper, et al., (2023), Hybrid solar thermal and heat pump systems in industry: Model based development of globally applicable design guidelines, Solar Energy Advances, vol. 3, no 1000034, doi: https://doi.org/10.1016/j.seja.2023.100034.

[3] J. F. Rosales-Pérez, et al., (2023), Hybrid system of photovoltaic and solar thermal technologies for industrial process heat, Energies, vol. 16, no. 5, doi: https://doi.org/10.3390/en16052220.

CONFERENCE TOPIC

This abstract refers to the following Conference Topics: Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications; IT Solutions and Artificial Intelligence

ARTIFICIAL INTELLIGENCE BASED MODEL PREDICTIVE CONTROL OF A SOLAR WATER HEATING SYSTEM

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SUMMARY

The solar water heating systems (SWHS) directly reduce reliance on fossil fuels, lowering greenhouse emissions and pushing the world closer to net-zero emission goals. Standard control systems, such as simple thermostats, are reactive and struggle to adapt, leading to wasted energy, unstable water temperatures, and a less reliable hot water supply. This work aims to develop an intelligent control system that integrates Artificial Intelligence (AI) with Model Predictive Control (MPC) to optimise the performance of a solar water heating system. Data from SWHS at the University of Botswana will be used to train a fast and efficient AI model. A smarter and more proactive system is expected from this work, which will boost thermal efficiency by 20-25% and reduce reliance on backup electricity by 15-20% compared to conventional methods.

INTRODUCTION

The Solar Water Heating Systems stand out as a solution for providing domestic and medium-scale industrial hot water, effectively reducing reliance on fossil fuels and lowering greenhouse gas emissions (Eze, 2024). However, as illustrated in Figure 1, the effectiveness of these systems is inherently limited by the unpredictable and unreliable nature of solar radiation and energy use, whether in residential or commercial industries. This variability, combined with fluctuating hot water demand, presents a complex control challenge that conventional strategies are ill-equipped to handle (Zhang, 2023). Widely used methods, such as ON/OFF thermostatic control or always-on pumping, are reactive and simplistic, leading to substantial inefficiencies (Wei, 2023).

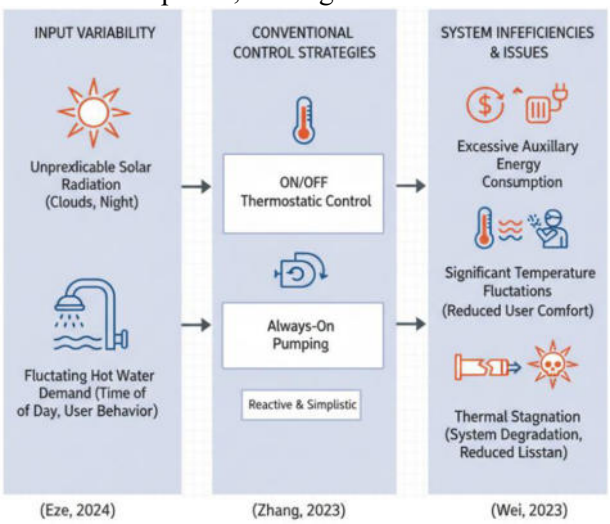


Fig. 1: Challenges of a solar water heating system

Model Predictive Control (MPC) has emerged as a powerful advanced control technique renowned for its ability to handle multivariable systems with constraints (Lee, 2022). It makes use of a dynamic model to predict future system states over a defined horizon and optimises control actions in the present, ensuring performance is maximised while adhering to system limits. Models like Computational Fluid Dynamics (CFD) require too much

processing power to run in real time, which limits their usefulness for on-the-fly control and creates a gap between theory and practice. To bridge this gap, this work proposes a framework that integrates AI with MPC.

METHODOLOGY

Data from real-life solar thermal systems will be used to train the AI system. Once trained, this AI can predict the system's future thermal state thousands of times faster, making it the ideal predictive engine for the MPC (Saloux, 2023). The performance of the final AI-based MPC system will be evaluated against benchmark controllers like a standard ON/OFF thermostat and a classic PID controller. The evaluation will be based on key performance indicators, including temperature regulation accuracy measured by RMSE, energy savings quantified by the percentage reduction in auxiliary heater runtime, and the system's robustness against unforeseen events like sudden weather changes.

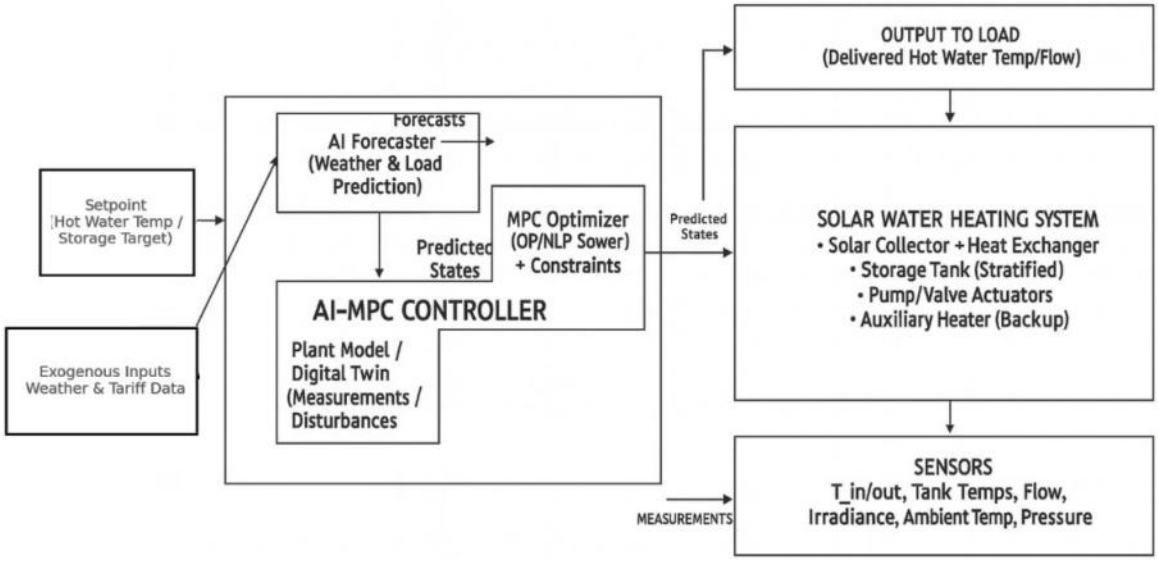


Fig. 2: Workflow of the AI-Based MPC solar water heating system

EXPECTED RESULTS

Integration of AI-based MPC will create a smart and proactive system, which will improve the efficiency of the system. A key outcome will be the ability of the system to consistently deliver a reliable supply of hot water, maintaining outlet temperatures within the optimal range of 60-70°C for both domestic and light industrial use in Botswana.

REFERENCES

Eze, F., Egbo, and M., Anuta, U.J. et al. A review on solar water heating technology: Impacts of parameters and techno-economic studies. Bull Natl Res Cent 48, 29 (2024). https://doi.org/10.1186/s42269-024-01187-1

Zhang, Z., Zhou, Y., Xin, X., Qian, J., & Liu, Y. (2023). A day-ahead operation regulation method for solar water heating based on model predictive control. Energy and Buildings, 301, 113715.

Wei, Z., Calautit, J. Evaluation of model predictive control (MPC) of solar thermal heating system with thermal energy storage for buildings with highly variable occupancy levels. Build. Simul. 16, 1915–1931 (2023). https://doi.org/10.1007/s12273-023-1067-4

Lee, D., Ooka, R., Matsuda, Y., Ikeda, S., & Choi, W. (2022). Experimental analysis of artificial intelligence-based model predictive control for thermal energy storage under different cooling load conditions. Sustainable Cities and Society, 79, 103700.

Saloux, E., Runge, J., & Zhang, K. (2023). Operation optimization of multi-boiler district heating systems using artificial intelligence-based model predictive control: Field demonstrations. Energy, 285, 129524.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: Section 1.13

Achieving the net-zero target in the cement indsutry

ABSTRACT

The drive toward net-zero emissions in heavy-industries such as cement and steel is critical to meeting global climate goals. Cement production in particular poses formidable challenges, as roughly **60 % of direct CO_2 emissions** arise from the calcination (chemical) process inherent to clinker production, and the remainder largely from fuel combustion in high-temperature kilns. In this work, we evaluate multiple configurations for net-zero cement production, evaluating technologically mature routes and trade-offs among capture, substitution, energy input, and cost. Key decarbonization pathways include:

- **Carbon Capture, Utilization, and Storage (CCUS):** Capture of CO_2 from both process and fuel combustion emissions offers one of the most mature and scalable routes toward net zero, though its deployment at scale requires extensive infrastructure (capture units, transport, storage), high capital investment, and supportive policy frameworks.
- **Clinker Substitution and Alternative Materials:** The use of supplementary cementitious materials (SCMs) (e.g. fly ash, slag, calcined clay, natural pozzolans) to reduce the clinker-to-cement ratio is a foundational lever. With current global average clinker factors around 70-75 %, reduction toward ~55-60 % is essential to substantially lower emissions.
- **Alternative Fuels and Energy Sources:** Transitioning kiln heat sources from fossil fuels to low-carbon alternatives such as biomass, waste-derived fuels, hydrogen, or electricity (where feasible) helps to address the fuel-combustion share of emissions. However, these alternatives often face limitations in availability, cost, and technical readiness.
- **Efficiency Improvements and Process Innovation:** Incremental gains via improved kiln design, energy recovery, optimized operations, and process intensification contribute to emissions reduction, but are insufficient alone to reach net zero.

Different trade-offs emerge for the analysis: for example, increasing the share of CCUS reduces emissions but at significantly higher cost; high up-front CAPEX, energy penalties, and the need for CO_2 transport/storage infrastructure create barriers. The cost of cement products is projected to rise under net-zero pathways, potentially requiring “green premiums” or subsidies, while policy uncertainty and regulatory risks may impede investment.

Comparative insights from the broader literature (e.g. Net-Zero Industry Trackers, OECD, Climate Bonds Initiative) reinforce that combination strategies are needed: no single lever will suffice. For steel plants, analogous principles apply: switching to low-carbon iron sources (e.g. hydrogen-based reduction), electrification, CCUS, recycling (scrap steel) are central components.

In sum, achieving net zero for cement plants is technically feasible, but hinges on early, large-scale deployment of CCUS; widespread adoption of clinker substitution; securing low-carbon energy supply; robust policy support (carbon pricing, incentives, regulation); and investment in enabling infrastructure. To be aligned with global temperature goals, these transitions must accelerate significantly in the next decade.

IMPROVING SUPERVISION OF COOLING TOWERS WITH COMPLEMENTARY MACHINE LEARNING

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SUMMARY

Reliable fault detection in industrial systems is critical but hampered by limited labeled data, interpretability and transferability. COMETH, an active-learning framework combining two ML models with expert-in-the-loop feedback, addresses these challenges. We applied it to eight cooling towers using three months of data labeled via predefined expert filters. During the application phase of the method, the models flagged measurements which could not be classified, requested expert feedback and were retrained iteratively on the new labelled data. Within 23 iterations, the F1 scores rose to 74% (DBSCAN) and 99% (decision tree), while the amount of manually labelled measurements dropped by 86%. We applied a transfer learning methodology to select one cooling tower from the compound as the best source system for transfer studies. These studies showed a further reduction in the labelling effort by 57%, whereas two cooling towers failed due to data gaps. Future work will explore clustering similar feedback requests to further reduce the workload of experts in the labelling process.

INTRODUCTION

Faults in industrial systems are frequent and can incur high operational costs, making reliable fault detection and diagnosis (FDD) essential [1]. Traditional rule-based FDD solutions offer clear logic and interpretability but are narrowly tailored, detect only predefined faults, and require manual reengineering when transferred between systems. As the availability of high resolution time-series data from sensors and actuators increases continuously, data-driven methods - particularly machine learning (ML) - offer greater adaptability than conventional mehtods. However, they face three key challenges: (1) scarcity of labelled fault data for supervised learning, (2) the need for interpretable outputs enabling operators to act on alarms, and (3) transferability across similar (sub-)systems to minimize the training effort [2].
COMETH [3] is an existing active-learning framework that addresses these challenges by combining two complementary ML models with expert-in-the loop feedback. When the models flag uncertain events, COMETH generates feedback requests to a domain expert. Expert interactions enrich the labelled dataset, improve model performance over time, and simultaneously offer reactivity. In this study, we apply COMETH to a cluster of industrial cooling towers and evaluate its ability to support manual FDD. In addition, we evaluate transfer possibilities of pretrained models across subsystems to further decrease the manual FDD effort.

METHODS

Our testbed is an industrial cooling plant, comprising next to other components a series of eight mechanically similar cooling towers (CTOs). Each tower is instrumented with inlet/outlet temperature sensors and the means to measure fan-speed and valve actuator positions. We collected three months of operational data in a cooling season with a resolution of five minutes.
First, a domain expert conducted a manual analysis of the data, identifying recurrent faulty operation modes such as sensor malfunctions, inefficient cooling operations and controls. These findings were encoded into automated

filters that label time-series segments as “nominal” or “faulty,” providing ground truth for both evaluation and the automated application of the COMETH framework.
During COMETH application, two ML classifiers - a density-based anomaly detector [4] and a decision-tree-based binary fault classifier [5] - are trained on the data of each CTO. The methods issue feedback requests whenever they disagree in classification at specific measurements. Expert labels (provided automatically by the defined filters, instead of live interaction) are used for retraining the methods iteratively on four-day data batches. We recorded the number of feedback requests and manually labelled measurements alongside ML performance metrics (sensitivity, specificity, F1-score) over successive iterations.
In a second experiment, we assessed the performance of the method when its pretrained on one source CTO and transferred to the others. We selected the source system by applying a transfer learning methodology developed in [6], which performs a statistical similarity analysis between the CTOs. Pretrained COMETH models from this system were transferred to the remaining towers, where the application is repeated as in the previous experiments. We compared the required amount of expert feedback against the amount needed when training models from scratch on each target CTO.

RESULTS AND CONCLUSION

The manual analysis revealed a variety of faulty operation modes but is laborious and has to be repeated for every subsystem. Applying COMETH yielded rapid improvements: within 23 feedback iterations, the number of manually labelled measurements decreased by approximately 86%, while the mean F1-score of the ML models rose to 74% for the DBSCAN algorithm and to 99% for the decision tree.
The similarity analysis resulted in the selection of CTO1 as the source system for our transfer studies. There, applications with pretrained models required about 57% fewer manually labelled measurements than applications with models trained from scratch, demonstrating effective reuse of learned representations. About 40% less feedback requests were necessary in these applications. The transfer failed however on two CTOs with a high amount of data gaps, underscoring the impact of data quality on transfer performance.
While we showed that the amount of feedback from an expert could be significantly reduced by applying the COMETH method and transferring pretrained models from one source system to several target systems, the amount of expert feedback is still a barrier for an efficient and cost-effective scaling of ML-based FDD methods. However, most feedback requests correspond to short time intervals, often limited to single measurements. In future works, we plan to investigate clustering techniques of similar requests to reduce the annotation effort.

REFERENCES

[1] Leite D., Andrade E., Rativa D., Maciel A.M.A., (2025), Fault Detection and Diagnosis in Industry 4.0: A Review on Challenges and Opportunities, Sensors, 25, 60
[2] Venkatasubramanian V., Rengaswamy R., Yin K., Kavuri S. N., (2003), A review of process fault detection and diagnosis: Part I: Quantitative model-based methods, Computers & Chemical Engineering, 27 (3), 293-311
[3] Benndorf G. A., Wystrcil D., Réhault N., (2018), A fault detection system based on two complementary methods and continuous updates, IFAC-PapersOnLine, 51 (24), 353-8
[4] Ester M., Kriegel H. P., Sander J., Xu X., (1996), A Density-Based Algorithm for Discovering Clusters in Large Spatial Databases with Noise, Second International Conference on Knowledge Discovery and Data Mining (KDD'96), Proceedings of a conference held August 2-4 226-331
[5] Wei-Yin L., (2011), Classification and Regression Trees, Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery, 1, 14-23
[6] Chavan K., Réhault N., Rist T., (2023), Transfer learning methodology for machine learning based fault detection and diagnostics applied to building services, Journal of Physics: Conference Series, 2600, 082038

CONFERENCE TOPIC

2.02. IT Solutions and Artificial Intelligence
2.07. Smart Services and System Operation

UNLOCKING GRID CAPACITY: THE CHALLENGE OF CLIMATE CHANGE FOR DYNAMIC THERMAL RATING

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SUMMARY

This study explores the potential of Dynamic Thermal Rating (DTR) to increase the capacity of the power voltage power grid in Styria, Austria. The challenges arising from the rapid need of renewable energy integration led to overhead lines (OHL) being at their limit considering the status quo usage under the assumption of worst-case weather conditions. To make use of the full capacity of the already installed OHL this study first analyzes historical weather data to show that DTR can significantly increase the capacity of existing OHL. It then uses regional climate change projections through 2040 from the "iKlimEt"-project to assess DTR's future effectiveness. While rising temperatures may reduce OHL capacity, shifts in wind patterns could counteract this effect. This study aims at evaluating the ties of DTR and climate change and therefore its long-term viability.
Keywords: Dynamic thermal rating, climate change, power system flexibility, grid modernization, ampacity, overhead transmission lines.

INTRODUCTION

The transition to a decarbonized energy system presents significant challenges to existing power grids, with congestion becoming an increasingly critical issue. Dynamic Thermal Rating (DTR) offers a promising, cost-effective solution to maximize the ampacity of existing overhead lines (OHL) by leveraging real-time weather conditions. This paper investigates the potential benefits and future viability of DTR for the high voltage grid in Styria, Austria, under ongoing renewable energy integration and climate change.

First, this study quantifies the potential increase in OHL capacity by applying the CIGRE 601 standard to a granular historical meteorological dataset for Styria. The analysis of past weather data, including wind speed, wind direction and ambient temperature, reveals the potential lying in the dynamic uprate of power lines, thereby enhancing grid flexibility and enable integration of further renewable energy sources or the mitigation of congestion. Second, the paper examines the long-term implications of climate change on DTR effectiveness through 2040. Utilizing regional climate projections for Styria coming out of the project "iKlimEt", the research assesses how anticipated shifts in weather patterns will impact the conductor ratings operated with DTR. The characteristics of the applied CIGRE 601 model (see Fig. 1) indicate that rising average ambient temperatures will likely exert a negative influence, potentially derating the possible maximal ampacity of conductors. Conversely, potential changes in wind patterns could either offset or benefit this effect.

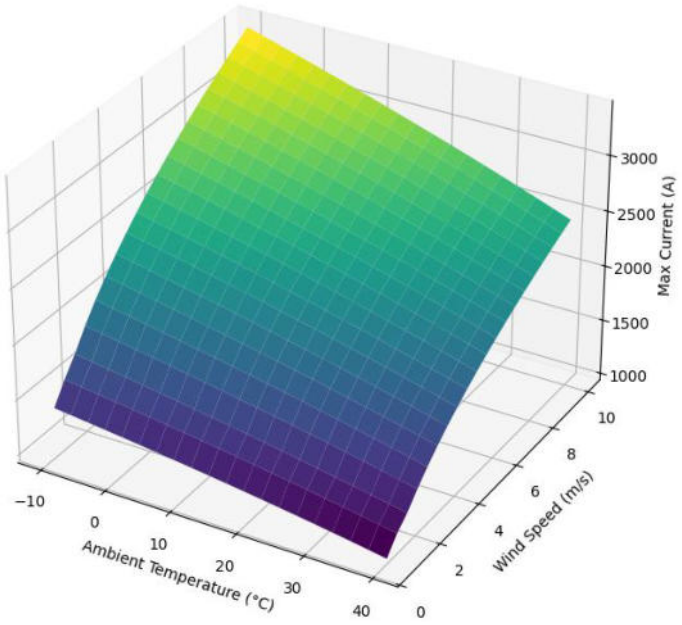


Fig. 1: Ampacity of an example conductor at different temperatures and wind speeds according to the CIGRE model.

SUMMARY AND OUTLOOK

This paper investigates the use of Dynamic Thermal Rating (DTR) as a solution for increasing the capacity of the high-voltage power grid in Styria, Austria. The research has two primary objectives. First, it quantifies the historical potential of DTR by applying the CIGRE 601 standard to a detailed set of past meteorological data (wind speed, direction, and ambient temperature). This analysis aims to establish a baseline for how much additional power could have been transmitted through existing overhead lines, thereby reducing grid congestion and facilitating the integration of more renewable energy in the existing infrastructure.

Second, the study projects the future effectiveness of DTR up to the year 2040 by incorporating regional climate change models. It hypothesizes that rising average temperatures will likely have a negative impact, reducing the maximum ampacity of the conductors. The overall long-term viability will therefore depend on whether potential changes in wind patterns can offset this heating effect.

Ultimately, the paper will provide crucial data for grid operators and policymakers. It will help determine whether DTR can be considered a sustainable, long-term strategy (by being a cheap alternative to building new power lines and therefore reducing the cost of the energy transition) or a temporary solution whose benefits may diminish as the climate warms, necessitating earlier investment in new grid infrastructure.

REFERENCES

[1] Iglesias, J., Watt, G., Douglass, D., Morgan, V., Stephen, R., Bertinat, M., ... & Nguyen, H. M. (2014). Guide for thermal rating calculations of overhead lines. CIGRE, Paris, France.

[2] FFG Projektdatenbank (no date) iKlimEt. Available at: https://projekte.ffg.at/projekt/5121747 (Accessed: 17 September 2025).

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

1.02. Building the Future: Smart Energy Infrastructure for the Energy Transition

THE MISSING LINK IN SOLAR THERMAL UPTAKE: A RHETORICAL ANALYSIS OF AWARENESS AND DISSEMINATION IN WINDHOEK

INTRODUCTION

Namibia possesses one of the highest solar irradiation potentials globally, rendering it an exemplary candidate for the adoption of renewable energy solutions, particularly solar thermal technologies. With approximately 300 sunny days and over 3,000 hours of sunshine annually, the country receives solar irradiation levels ranging from 2,200 to 2,400 kWh/m² per year—figures that substantially surpass the African average. Nevertheless, despite this considerable potential, the uptake of solar energy technologies in urban areas such as Windhoek remains limited; recent reports indicate that fewer than 10% of households in Namibia utilise solar energy for cooking, heating, or lighting, according to data from the Namibia Statistics Agency (NSA).

This paradox prompts critical inquiry into the roles of communication, marketing, and dissemination in the implementation of sustainable energy solutions. It is pertinent to consider whether the missing link lies in the rhetorical strategies employed to frame, promote, and facilitate the public and local authority understanding of clean energy initiatives.

This study will then examine the rhetorical dimensions of solar thermal sustainability, arguing that effective dissemination and persuasive communication are crucial for implementation efforts to succeed. At the same time, based on the three main questions: What rhetorical strategies can drive interest in solar geysers in Windhoek, how marketing and dissemination can be tailored to local cultural and economic contexts, and what role does lack of awareness play in the uptake of solar geysers? While focusing on rhetorical analysis of current local solar geyser campaigns.

This paper proposes a framework of rhetorical strategies, grounded in local values, economic realities, and cultural narratives, to enhance uptake of solar geysers in Windhoek, Namibia. Rhetoric is not just about language but it is about shaping public perception and action.

REFERENCES:

GIZ. (2022). *Sector brief Namibia: Renewable energies*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. *Retrieved* September 15, 2025, from https://www.giz.de/en/downloads/giz2022-en-sector-brief-namibia-renewable-energy.pdf

SEASONAL PERFORMANCE OF A PHOTOVOLTAIC ARRAY WITH HYBRID BATTERY–SUPERCAPACITOR STORAGE: A CASE STUDY FOR BOTSWANA

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SUMMARY

This paper investigates a photovoltaic (PV) array supplying an alternating rural load supplemented with a hybrid battery–supercapacitor energy storage system. A MATLAB/Simulink model was formed from Botswana summer and winter season typical seasonal irradiation and temperature profiles. The findings illustrate that summer provides greater total PV generation but with lower use efficiency due to afternoon cloudiness and hilly cycling, and lower energy but improved use in clear weather during winter. The battery–supercapacitor system improved system ruggedness. The results identify Hybrid PV–Battery–Supercapacitor systems to be economically valuable both in enhancing efficiency and reliability for Botswana's rural electrification. Seasonal analysis puts into focus system designs that both mitigate abundance as well as variability of energy, supplemented with optimal storage capacity sizing and load-shifting strategies for the best utilisation of capacities.

INTRODUCTION

While promising, PV systems are confronted with the innate randomness of solar irradiation and energy production mismatch with load demand. These issues are worst in rural Botswana, which has demand profiles dominated by sharp evening peaks, intermittent commercial loads such as refrigeration, and instant motor-start loads for water pumping (Samikannu, 2022). In the lack of energy storage, variability can compromise the reliability and efficiency of PV-based systems. Through this research, it is anticipated that a contribution towards the growing body of literature on hybrid renewable energy systems will be made, and Botswana-specific information produced that can influence rural electrification policy, guide investment, and future experimental development of hybrid PV–storage technologies.

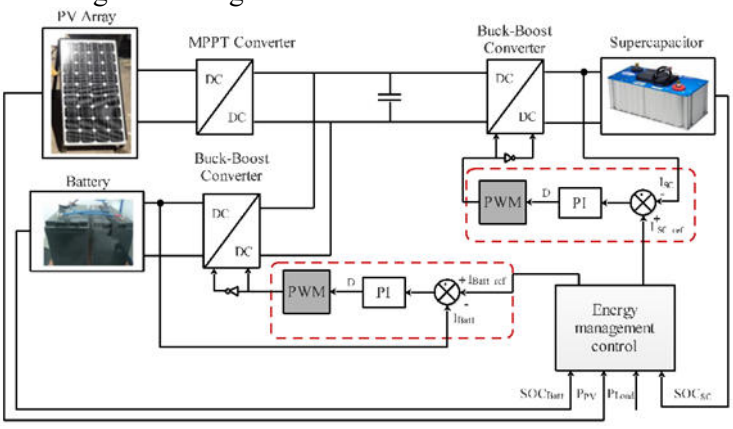


Fig. 1: Optimised Power Management for Photovoltaic Systems with Hybrid Battery-Supercapacitor Storage Formatting

METHODOLOGY

The PV subsystem is based on the single-diode equivalent model that represents a compromise between complexity and accuracy (Nordin, 2021). The PV output current is expressed as:

$$I_{pv} = I_{ph} - I_0\left(e^{\frac{q(I_{pv}+I_{pv}R_S)}{nkt}}\right) - \frac{V_{pv}+I_{pv}R_S}{R_{sh}}$$

Where I_{ph} is photocurrent (proportional to irradiance), I_0 the reverse saturation current, R_S and R_{sh} series and shunt resistances, q the electron charge, k the Boltzmann constant, and T the operating temperature. The Battery state of charge (SoC) is described by:

$$SoC(t) = SoC(t-1) + \frac{n_{ch}I_{ch} - \frac{I_{dis}}{I_{dis}}}{C_{bat}}$$

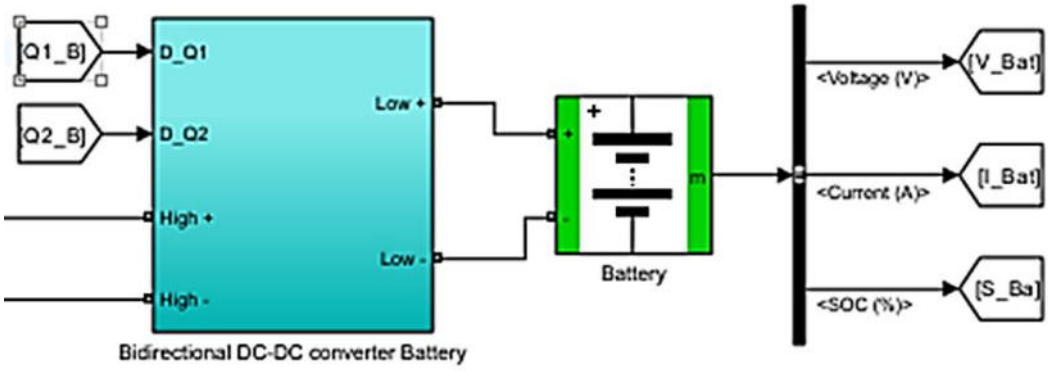


Fig. 2: Simulink Model snippet of supper-capcitor

The load is modelled as a time-varying demand, from rural Botswana usage profiles (Kiravu *et al*., 2022). This was simulated in Simulink using a programmable variable load resistance.

RESULTS

Table 1: Seasonal Performance Metrics of the PV–Battery–Supercapacitor Hybrid System

Metric	Summer (Nov–Mar)	Winter (May–Aug)	Key Insight
PV Energy Harvested (kWh/day)	16.95	14.67	Summer has higher irradiance but with more variability.
Energy Delivered to Load (kWh/day)	9.24	8.68	Winter delivers slightly less absolute load energy, but more efficient utilisation.
PV Utilisation (%)	54.5	59.2	Winter's smooth irradiance yields better alignment with demand.
Battery SoC Range (%)	25–90	30–90	Summer cycling is deeper and faster; winter is smoother.
Supercapacitor Voltage Dip (V)	45.0 → 44.3	45.0→ 44.3	Nearly identical seasonal response; SC is unaffected by long-term irradiance.
Peak Battery Current w/o SC (A)	~52	~52	High stress was observed in both seasons without SC support.
Peak Battery Current w/ SC (A)	~10–12	~10–12	~80% current reduction, consistent across seasons.
Stress Mitigation by SC (%)	~80	~80	Confirms the universal benefit of SC integration.

REFERENCES

Samikannu R. (2022). An Assessment and Design of a Distributed Solar PV System for Rural Applications, Int. Transactions on Electrical Energy Systems.

Nordin, N. A. (2021). Integrating Photovoltaic Solar Cells and Supercapacitors for Sustainable Energy Devices: A Review, Energies, vol. 14, no. 7211.

Kiravu C., Emili S., Magole L., Jeffrey A. M., Mbekomize C., *et* al. (2022). Mmokolodi solar PV project – demonstrating sustainable renewable energy system design and potential for Botswana rural electrification, Botswana International University of Science and Technology.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: **Section 1.07**

EVALUATING CIRCULARITY IN LIFE CYCLE ASSESSMENT BASED ON THE CASE STUDY *ZIEGELWAND REUSE*

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SUMMARY

The construction sector is a major driver of resource use and GHG emissions, yet current building LCA practice captures circularity benefits only at end-of-life (Module D), leaving reuse and substitution effects in the construction phase invisible. To address this, the enhanced flexibility of the newly developed FprEN 15978 is utilised to systematically quantify avoided burdens from reusing and recycling components during the construction phase, supported by the Material Circularity Indicator and Disassembly Potential Indicator. A supermarket case study over 50 years using modular, prefabricated components designed for disassembly shows that the extended framework makes reuse benefits transparent, highlights substantial emission savings, and strengthens incentives for circular building practices.
Keywords: Life Cycle Assessment, Circular Economy, Design for reuse, Module D, Sustainability

INTRODUCTION

The construction sector accounts for almost 50% of annual global material use [1, 2] and 36% of greenhouse gas (GHG) emissions, with resource consumption expected to more than double between 2017 and 2060 [2]. Circular economy strategies therefore gain increasing importance [3]. European regulations such as the EU-Taxonomy [4] and the new ISO standards for circularity (ISO 59004/10/20) promote or require their implementation. In building Life Cycle Assessment, circularity measures are currently primarily considered at the end-of-life in Module D1 [5]. Although EN 15978 allows credits from reuse, recycling or energy recovery, practice shows inconsistent reporting, often limited to energy recovery or basic metal recycling [6]. Component reuse or broader material recycling are rarely explicitly quantified. As a result, avoided burdens from using secondary materials during construction remain explicitly unreported, as design-for-circularity is seldom modelled due to complexity. This makes circular benefits largely invisible and offers little incentive for adoption. To address this, we propose a simple approach to better capture reuse and recycling benefits within the current Module D and a Module D^A that represents avoided burdens during construction (Module A) according to the principles of FprEN 15978 [7].

METHOD

The proposed methodology builds on the modular structure of FprEN 15978, introducing an additional Module D^A alongside the conventional Module D1. To operationalize this framework, two established indicators, the Material Circularity Indicator (MCI) [8] and the Disassembly Potential Indicator (DPI) [9] are applied. Based on these indicators, the share of materials and components that can realistically be reused or recycled is calculated. The method allows reporting benefits of end-of-life reuse and recycling of material flows outside the system boundary in the current Module D and avoided burdens from the use of reuse and recycling components / materials during construction (Module A) separately in Module D^A. It can be applied both in new construction

and renovation projects and enables systematic accounting of emission savings from circular design, construction and deconstruction, making substitution effects transparent and strengthening incentives for circularity.

CASE STUDY

Supermarkets have an average service life of about ten years, after which demolition and reconstruction are common. Therefore, this typology has high potential for reuse-oriented construction systems. As part of the research project *Ziegelwand REUSE*, a reusable wall system was developed by *wienerberger* and *TU Graz* and tested in a pilot supermarket in Vienna-Kagran, offering around 900 m² of wall surface suitable for the REUSE system. The first application cycle models the initial installation and one conversion. Further implementations are planned in Graz and Carinthia. The case study assesses two scenarios over 50 years, covering five consecutive supermarket life cycles: (1) REUSE scenario – Prefabricated wall elements are dismantled and reused every ten years at different supermarket sites. (2) Conventional scenario – Each supermarket is built with virgin materials, requiring five complete material cycles over the 50 years. Both scenarios are assessed using (i) only the module D at the end of life and (ii) the proposed extended framework including Module D^A. In the conventional approach, Module D only records benefits from recycling at end-of-life. By contrast, the extended framework's Module D^A additionally reports avoided burdens from repeated reuse of the wall system in subsequent construction cycles.

RESULTS

The proposed approach building on EN 15978 with Module D^A closes a critical methodological gap concerning circularity in building LCA and provides a more holistic view of environmental performance. The case study demonstrates the practical application and added value of the approach by showing the benefits of reusing components and materials over multiple life cycles, tracking them over 50 years rather than at a single site.

REFERENCES

[1] Meglin, F., Kytzia, S. and Habert, G. (2021) Regional circular economy of building materials: Environmental and economic assessment combining Material Flow Analysis, Input-Output Analyses, and Life Cycle Assessment. Journal of Industrial Ecology, 26(1).
[2] OECD (2019), Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences, OECD Publishing, Paris.
[3] Finamore, M., & Oltean-Dumbrava, C. (2024). Circular economy in construction—Findings from a literature review. Heliyon, 10(15), e34647.
[4] European Union. (2020). Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 (EU Taxonomy Regulation). Official Journal of the European Union, L 198, 22.6.2020.
[5] Austrian Standards International (ASI). (2011). ÖN EN 15978:2011: Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method. European Committee for Standardization (CEN).
[6] Delem, L., & Wastiels, L. (2019). Module D in the Building Life Cycle: Significance Based on a Case Study Analysis. IOP Conference Series: Earth and Environmental Science, 290(1), 012042.
[7] Austrian Standards International (ASI). (2025). FprEN 15978:2025: Sustainability of construction works – Assessment of environmental performance of buildings – Requirements and guidance (Final Draft). European Committee for Standardization (CEN).
[8] Ellen MacArthur Foundation (2015). Circularity Indicators – An approach to measuring circularity: Methodology. Ellen MacArthur Foundation, Cowes, UK.

[9] Van Vliet, M., van Grinsven, J., & Teunizen, J. (2021). Circular Buildings: Disassembly Potential Measurement Method Version 2.0. Alba Concepts / Dutch Green Building Council (DGBC).

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: Life Cycle Assessment

HIGH FLUX HEAT TRANSFER FOR CONCENTRATED SOLAR TECHNOLOGY APPLICATIONS

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SUMMARY

This abstract describes a receiver for point-focusing concentrated solar technology applications and gives a comparison for three different heat transfer media. Computational fluid dynamics (CFD) simulations were performed for the optimization of the helical tube receiver design and operation. The central aim was to determine operating conditions for three heat transfer media where local overheating is avoided.
Keywords: Concentrated solar thermal, receiver, heat transfer media, CFD

INTRODUCTION

Concentrated solar thermal (CST) technologies can provide high temperatures needed for industrial thermal applications. Approximately 80% of the solar irradiation can be transferred into a heat transfer medium. This technology is also known for its robust setup and over 30 years of operational experience.
At a thermal power of 0.5 MW/m^2 and more, the heat should be dissipated properly to avoid local overheating and degeneration of the heat transfer media. (Local) overheating is here defined as the temperature difference between the maximum and mean temperatures at the outlet.

EXPERIMENTAL SETUP

The single-branch helical tube receiver was designed with a setup that allows for quick emptying, which is necessary when using liquid sodium as a heat transfer medium. For this study, we assumed uniform, symmetric radiation along a vertical axis inclined at 30° to represent perpendicular radiation conditions at 0.5 MW/m² (see Figure 1).

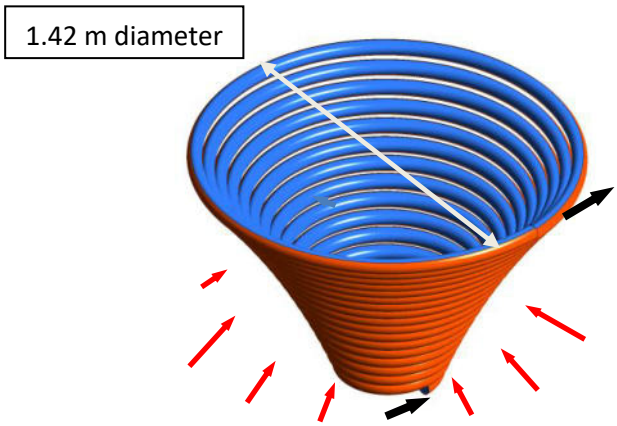


Fig. 1: Left: Geometry of the receiver with inlet and outlet (black arrows) and main direction of the concentrated sun irradiation (red arrows). Heated surface: orange, non-heated surface: blue.

Geometry:

Diameter: 1.42 m

Height: 0.72 m

Radiated surface area: 1.07 m²

Outer tube diameter: 36 mm

Wall thickness: 1.5 mm.

The wall material is Inconel 690.

Solar salt is considered as composition of 60% $NaNO_3$ and 40% KNO_3.
Helisol® XLP "in use" by Wacker Chemie AG was selected as silicon oil. The maximum possible temperatures

for continuous operation at the liquid-solid interface of the irradiated surface were 890°C for sodium (at 1 bar), 550°C for solar salt, and 425°C for Helisol. The heat flux was set to a constant value of 0.5 MW/m^2.
For the model, an unstructured mesh with inflated boundary layers was generated. In order to obtain y^+ values close to 1, the boundary layer inflation starting at a spacing of 0.005 mm was used. The mesh was created by using Pointwise software with 5.8 million cells. RANS calculations were performed by using an Omega Reynolds stress turbulence model with ANSYS CFX.

RESULTS

The three heat transfer media differ primarily in their thermal conductivity, which ranges from 0.078 (silicon oil) and 0.48 (solar salt) to 72.3 (sodium) W m^{-1} K^{-1} (@ 425°C). Thus, the values differ by nearly three orders of magnitude when comparing sodium and silicon oil.
To investigate these differences in a CST receiver, a CFD study was conducted with a step-wise variation of the inlet speed until the maximum outlet temperature was reached and without exceeding the maximal possible temperature.

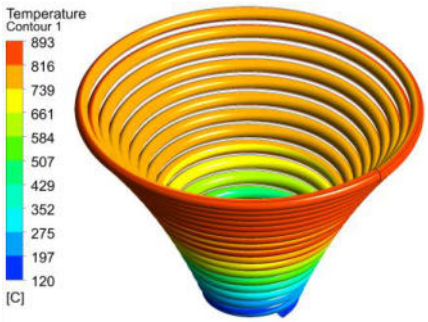


Fig. 2: Temperature contour plot of an ANSYS CFX simulation. Heat transfer medium: Sodium. Inlet temperature: 120°C, average outlet temperature: 838°C, 0.33 m/s flow velocity, 0.5 MW/m²

Figure 2 shows the heat distribution at the fluid-solid interface when sodium is used as the heat transfer medium. The temperature rises from the inlet (bottom) to the outlet (top) of the receiver, with a significant difference in temperature between the inside and outside of the tubes.

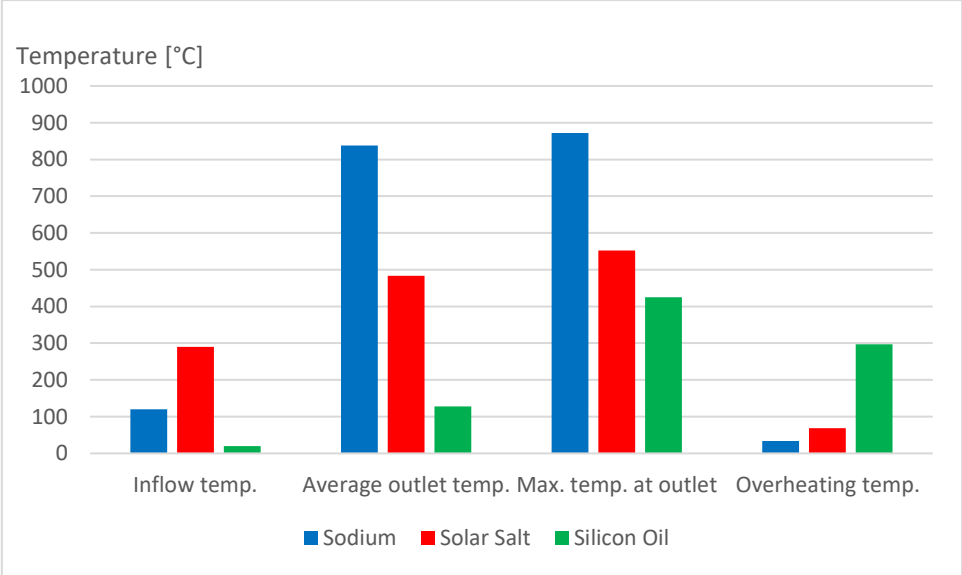


Fig. 3: Results for reaching maximal temperature at the solid-fluid interface. Inflow velocities: sodium: 0.3 m/s, solar salt: 1.9 m/s, silicon oil: 1.7 m/s.

Figure 3 plots the results for the three fluids showing their respective inflow temperatures. Using sodium as the heat transfer medium results in the least overheating at only 38°. This is followed by solar salt at 69°C and silicon

oil, at 297°C. Sodium has the highest maximum attainable average outlet temperature (838°C). However, there is a trade-off between geometry, thermohydraulic properties, and operating conditions due to handling limitations, despite sodium's favorable heat transfer capabilities.

Further results will include adapting the design for fluids especially with low heat conductivity, such as silicon oil, by varying the tube diameter.

REFERENCES

C. Turchi, S. Gage, J. Martinek S. Jape, K. Armijo, J. Coventry et al. 2021. CSP Gen3: Liquid-Phase Pathway to SunShot. Golden, CO: National Renewable Energy Laboratory, NREL/TP-5700-79323, https://www.nrel.gov/docs/fy21osti/79323.pdf

Fraunhofer-Institut für Solare Energiesysteme ISE und Bundesverband Solarwirtschaft e. V. (2025): „Solare Prozesswärme für die deutsche Industrie – Ertrag und Wirtschaftlichkeit im Vergleich zu konventioneller Wärmeversorgung“, Freiburg und Berlin

J. Fuchs, M. Böttcher, “CFD Study of a Sodium High-Flux Receiver Designed for Additive Manufacturing”, AIP Conference Proceedings, in print

CONFERENCE TOPIC

1.12. Next-Generation Technologies for Renewable Energy and Resource Efficiency

OPTIMIZATION OF CO_2 EMISSION TAXATION IN SWITZERLAND USING MACHINE LEARNING

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SUMMARY

This research investigates how Machine Learning can optimize CO_2 taxation of passenger cars in Switzerland. Using OBFCM data, The Hotmaps data, SFOE OpenGIS4ET data and predictive models (LightGBM, Random Forest), it shows that real emissions can be estimated more accurately from vehicle characteristics such as weight, power, and engine displacement than from WLTP values. Expert and political validation supports reforming cantonal taxation—especially for hybrids—replacing the A–G energy label with continuous indicators, and building a fairer, more climate-aligned tax system.

ABSTRACT

This research aims to optimize CO_2 emission taxation of internal combustion engine (ICE) passenger vehicles in Switzerland using a Machine Learning (ML) approach. The current tax system has limitations, particularly because it relies on WLTP homologation values, which often differ significantly from real-world vehicle consumption.
Using European OBFCM data, The Hotmaps data and SFOE OpenGIS4ET data, this study develops predictive models to estimate real-world fuel consumption—and thus CO_2 emissions—based on technical vehicle characteristics such as weight, power, and engine displacement. The performance of ensemble algorithms like LightGBM and Random Forest demonstrates ML's ability to accurately predict consumption and emissions.

The flow below (see Fig.1) represents all the data processing and analysis steps, organized sequentially to transform raw data into usable results, integrating operations such as import, preparation, modeling, and export (see Fig.1)

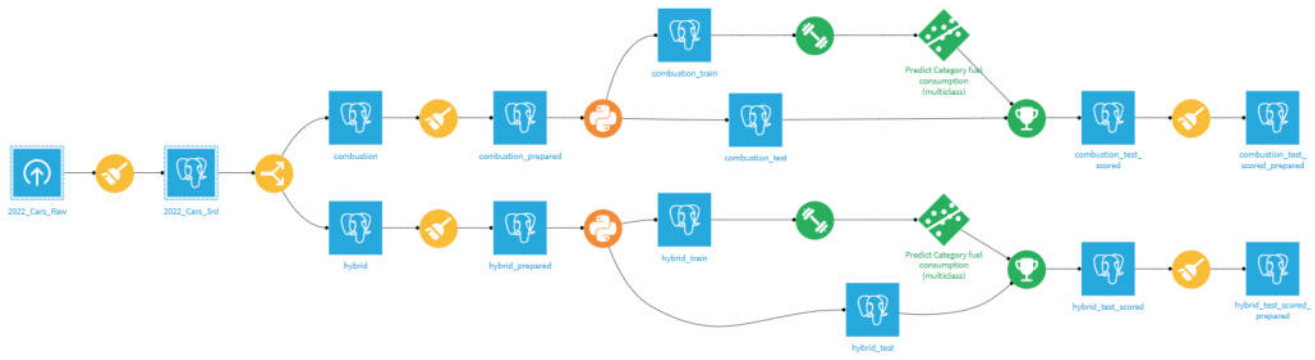


Fig. 1: Data processing and analysis steps

To ensure model robustness, qualitative validation was conducted using the Delphi method with mobility experts, a questionnaire targeting Swiss corporate fleet managers, and interviews with politicians from various Swiss political parties. These steps root the recommendations in Switzerland's political and economic realities.
The results suggest the need for revising cantonal taxation to better reflect real emissions and to more strictly regulate hybrid vehicle taxation. The study proposes introducing a differentiated, science-based tax system that could help Switzerland meet its climate goals while enhancing tax fairness.
This work shows that in Switzerland, a fairer and more environmentally conscious vehicle tax system can be built through ML models capable of accurately predicting real CO_2 emissions of ICE and hybrid vehicles from their technical specifications. Weight, power, and engine displacement emerge as more relevant fiscal levers than current criteria. This ML-driven approach, validated by experts and political stakeholders, opens the way for a differentiated tax system better aligned with vehicles' real environmental impacts.
The study also recommends increasing public awareness, improving the assessment of hybrids (whose emissions are often underestimated), and abandoning the A–G energy label in favor of more precise and continuous indicators for a tax system truly aligned with vehicles' environmental impact.

SYNTHESIS OF ML MODEL RESULTS

This synthesis confirms that the ML model offers a robust approach to predicting and classifying vehicle CO_2 emissions based on their intrinsic characteristics. It also supports the relevance of a differentiated tax policy based on precise, individualized predictions aligned with the technical realities of the Swiss and European vehicle fleets

Table 1 Summary of the Machine Learning Model

Category	Main Results
Datasets	OBFCM european dataset. Technical characteristics and real consumption of vehicles
Key correlations	Total distance traveled ↔ Total fuel consumed Average consumption ↔ CO_2 emissions (WLTP) Engine power ↔ Engine displacement Electric range ↔ Reduction in overall consumption |
Influential Variables	With official data: WLTP emissions = most important variable Without official data: Fuel type, powertrain mode, vehicle mass, engine power, engine displacement
Algorithmic Performance	Best performance achieved with ensemble learning algorithms such as LightGBM, Random Forest, and Gradient Boosted Trees.
Observed Limitations	To overcome the difficulty of distinguishing the intermediate consumption levels, a continuous approach will provide better results.
Recommendations	Increase the volume and quality of data. Integrate additional variables (e.g., driving cycle, detailed electric consumption). Adjust classification thresholds and hyperparameters
Political & Fiscal Impact	ML enables precise association of technical characteristics with emissions and helps define tax brackets better calibrated to the environmental performance of vehicles.

RECOMMANDATIONS

At the conclusion of this study, several recommendations can be made for policymakers and stakeholders in the Swiss automotive sector:
1. Implement a differentiated taxation system based on real-world fuel consumption: The current tax system often relies on homologation values that poorly reflect actual usage. Machine Learning algorithms enable the estimation of real-world consumption based on reliable technical characteristics such as vehicle mass, engine displacement, or power.

2. Include vehicle mass and power in fiscal brackets: These variables have a significant impact on real CO_2 consumption and emissions. A taxation framework that incorporates them would be fairer and more environmentally sound.
3. Standardize taxation across cantons: The proposed fiscal model could help harmonize tax practices among Swiss cantons, avoiding regional disparities and inconsistencies.
4. Ensure continuous monitoring using OBFCM data: The development of onboard fuel consumption monitoring systems (OBFCM) presents an opportunity to regularly reassess the relevance of tax scales based on real-world data.
5. Raise consumer awareness: Fiscal measures should be accompanied by public awareness campaigns to help users understand the environmental impact of their vehicle choices.
6. Further research on hybrid and electric vehicles: Findings indicate that hybrids tend to have underestimated real-world emissions. A tailored fiscal framework should more accurately account for these discrepancies.
7. Avoid reliance on the A–G energy scale: This work did not use the A–G energy label scale because its class distinctions are too narrow and do not reflect actual differences in consumption or emissions. This categorization lacks the precision required to train a reliable Machine Learning model, which depends on continuous and detailed data for accurate predictions

REFERENCES

Liao, Y., Tozluoğlu, Ç., Sprei, F., Yeh, S., & Dhamal, S. (2023). Impacts of charging behavior on BEV charging infrastructure needs and energy use. Transportation Research Part D: Transport and Environment, 116, 103645. https://doi.org/10.1016/j.trd.2023.10364

Magnaval, G., & Boulay, A.-M. (2025). Development of an analytical model of automobile energy consumption during use-phase for parametrized life cycle assessment. Renewable and Sustainable Energy Reviews, 217, 115716. https://doi.org/10.1016/j.rser.2025.115716.

SFOE. (2021-2026). "OpenGIS4ET – Open Geographic Information System for Energy Transition" [Research project SI/502364]. Swiss Federal Office of Energy.

The Hotmaps project (open source mapping and plannng tool for heating and cooling): https://www.hotmaps-project.eu

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
2.03. Just and inclusive mechanism for the energy transition
2.01. Financing and Business Models
2.05.Marketing, dissemination and implementation strategies

TESTING OF AIR-BRINE COLLECTORS FOR USE AS SOLE HEAT SOURCE FOR HEAT PUMPS

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SUMMARY

Air-brine collectors as sole heat source for heat pumps are typically operated below ambient temperature and during nighttime. These operating conditions are not considered so far by the ISO 9806 standard [1] which is used for the characterisation of the thermal performance of air-brine collectors. Within the project SolAirHX a definition of air-brine collectors and a classification of the different products on the market was elaborated as well as an adopted test procedure for a faster, more reliable and reproducible determination of the collector parameters was developed.
Keywords: Air-brine collectors, PVT, heat pump, test procedure

INTRODUCTION

Air-brine collectors are solar collectors that can use ambient heat as well as solar radiation to generate heat. This means that, if correctly dimensioned, they can be used as the sole heat source for brine-water heat pumps. Air-brine collectors can be designed as solar thermal air-brine collectors. In this case, the incident solar radiation is converted exclusively into heat. Alternatively, they can be designed in combination with PV modules as PVT air-brine collectors, so that the solar radiation can be used to generate heat and electricity, see Figure 1.

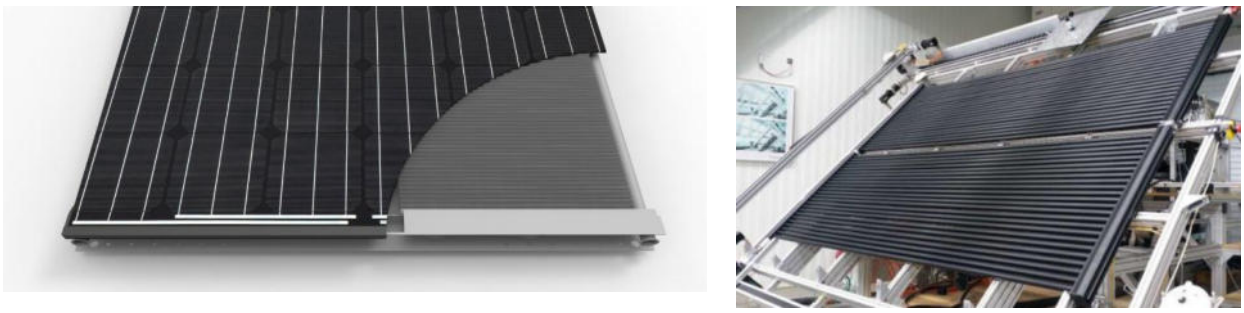


Fig. 1: Examples of air-brine collectors, on the left a PVT air-brine collector, on the right a solar thermal air-brine collector

Knowledge of the thermal performance of air-brine collectors is necessary for the correct design of the collector field for a given heat pump. In order to determine this reliably, a test procedure based on ISO 9806 [1] was developed in the SolAirHX project. This is based on the model specified in [1], see Eq. 1, for modelling thermal performance.

$$\dot{Q} = A_G \begin{bmatrix} \eta_{0,b} K_b(\theta_L, \theta_T) G_b + \eta_{0,b} K_d G_d - a_1(\vartheta_m - \vartheta_a) - a_3 u(\vartheta_m - \vartheta_a) \\ +a_4\left(E_L - \sigma {T_a}^4\right) - a_5\left(\frac{d\vartheta_m}{dt}\right) - a_6 uG \end{bmatrix} \quad \text{(eq. 1)}$$

RESULTS

After intensive research in the Project SolAirHX deviant from [1], the following test procedure was established:

1. Determination of parameter a1 in an indoor or outdoor test in calm conditions and without solar radiation.
2. Performance of an outdoor measurement in accordance with ISO 9806, supplemented by measurements without solar radiation and negative temperature differences between the average fluid and ambient temperature.
3. Parameter identification is carried out in accordance with ISO 9806 under the following boundary conditions:
    - Parameter a_1 determined under 1. is fixed.
    - $a_4 = 0.5$
    - $a_6 = 0.05$ s/m
    - $K_d = 1$

   The unusual specification of parameters for a test procedure is possible in this case because a detailed simulation study showed that the parameters a_4, a_6, and K_d play a minor role in the annual performance factor in the simulation.

   The test procedure developed has been proposed for inclusion in the current revision of ISO 9806. It is expected that revision is published by the end of the year including the proposed test procedure.

   The article defines air-brine collectors and introduces a classification of the different types of construction. Furthermore, the results obtained using the new test procedure are compared with those obtained using the test procedure described in [1] and the advantages of the new test procedure are explained.

REFERENCES

[1] ISO 2017. ISO 9806:2017: Solar energy — Solar thermal collectors — Test methods, 2017

ACKNOWLEDGEMENTS

The research project ‘Development of a test procedure for air-brine collectors as a heat source for heat pumps’, acronym ‘SolAirHX’, is funded by the German Federal Ministry for Economic Affairs and Climate Protection via the project management agency Jülich (PTJ) under the funding code 03TN0046 A, based on a decision by the German Bundestag, and is also supported financially and substantively by the participating industrial partners. The authors would like to express their gratitude for this support.

CONFERENCE TOPIC

1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

ECONOMIC COMPARISON OF DIFFERENT HEAT PUMP HEATING SYSTEMS IN SINGLE FAMILY HOUSES

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SUMMARY

Costs (investment costs, operation costs, maintenance costs, disposal costs, life cycle costs, heat production costs) have been assessed and calculated for four different heat pump systems in German single family houses (new and stock).
Keywords: Life cycle costs (LCC), levelized cost of heat (LCoH), heat production costs, heat demand, heat pump systems

INTRODUCTION

A wide range of factors play a role in the ecological and economic assessment of systems and components for heat supply in residential buildings over their life cycle. The 'Efficient Heating' project, initiated by Fraunhofer ISE, Fraunhofer IBP and the Institute for Building Energy, Thermotechnik und Energiespeicherung (IGTE) at the University of Stuttgart and carried out in collaboration with representatives from the heating, real estate and planning industries, aims to identify and evaluate the underlying complex interrelationships and make them comparable across different technologies.
For a fair comparison of the costs of different heating technologies, a uniform procedure, reference buildings, cost models and boundary conditions for the economic calculation were defined [1], [2], [3]. In addition, the different heating technologies in the reference buildings were simulated in an annual simulation to determine the respective energy requirements [4], [5].
This article presents, compares and discusses the investment costs, total lifecycle costs (LCC) and the levelised cost of heat (LCoH) of the following heat pump systems in single-family homes (existing and new buildings) over a period of 25 years:

1. Air-water heat pump
2. Geothermal heat pump
3. Brine-water heat pump with PVT collector as heat source
4. Solar thermal combination system with air-water heat pump

The calculation takes into account the costs of investment, operation, maintenance and servicing, as well as disposal, and the income from subsidies, any feed-in tariffs and the residual value.

REFERENCES

[1] Nienborg, B. et. al.: Repräsentative Lastprofile von Wohngebäuden für die ganzheitliche ökologische und ökonomische Bewertung von Heizungstechnologien, Beitrag zum 33. Symposium Solarthermie und innovative Wärmesysteme 2023, Bad Staffelstein, ISBN 978-3-948176-22-8

[2] Stephan Fischer, Karl-Anders Weiß, Björn Nienborg, Katrin Lenz: Uniform Modeling of Heat Production Costs in Single-Family and Multi-Family Houses, Vol. 1 (2024): ISEC 2024 – 3rd International Sustainable Energy Conference, https://doi.org/10.52825/isec.v1i.1156

[3] Fischer, S.: Definition der Randbedingungen zum ökonomischen Vergleich von Heizungstechnologien in Ein- und Mehrfamilienhäusern, Beitrag zum 34. Symposium Solarthermie und innovative Wärmesysteme 2024, Bad Staffelstein, ISBN 978-3-948176-26-6

[4] Bachmann, S., Fischer, S.: Definition generischer Heizungsanlagen für den ökonomischen und ökologischen Vergleich, Beitrag zum 34. Symposium Solarthermie und innovative Wärmesysteme 2024, Bad Staffelstein, ISBN 978-3-948176-26-6

[5] Bachmann, S., Fischer, S.: Definition generischer Heizungsanlagen für den ökonomischen und ökologischen Vergleich – Teil 2, Beitrag zum 35. Symposium Solarthermie und innovative Wärmesysteme 2025, Bad Staffelstein,

ACKNOWLEDGEMENTS

The research project " Systematic investigation and evaluation of the economic and environmental sustainability of solar-based renewable heating systems in comparison with alternative systems", acronym "Effizientes Heizen", was funded by the Federal Ministry for Economic Affairs and Climate Action via the Project Management Organisation Jülich (PTJ) based on a resolution of the German Bundestag under the funding code 03EN6014A and B, as well as supported financially and in terms of content by the participating industry partners. The authors would like to thank all partners and colleagues involved for their excellent support, cooperation and commitment to the projects and take responsibility for the content of this paper.

CONFERENCE TOPIC

2.04. Life Cycle Assessment

FLEXIBILITY SERVICE IMPLEMENTATION FOR SOHO AS PILOT OF THE OPTIX PROJECT

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ABSTRACT

This paper presents findings from a residential flexibility service pilot implementation conducted as part of the OPTIX project. The OPTIX project lead by DTU, is funded within CETP and aims to optimize the energy performance of urban districts through interoperable digital platforms.

The pilot was deployed in a small office/home office (SoHo) environment comprising both office and residential spaces. Two Raspberry Pi-based Python applications were developed to demonstrate demand response capabilities by consuming weather forecasts and flexible tariff data, generating control decisions, and managing connected appliances and smart plugs.

The pilot serves as validator for:

- accessibility of appliances
- availability of signals
- cyber security
- evaluation of effect

Later the connection to energy communities getting signals about their balance will be explored.

Key Technical Challenges and Solutions: The implementation revealed several practical obstacles in residential flexibility services. Initial smart plug integration using reverse-engineered libraries proved problematic across different system environments, ultimately requiring a change in plug hardware after extensive troubleshooting efforts. The Python dependency chain exceeded 30 packages, resulting in long startup times on Raspberry Pi Zero, and RPi 3 hardware. Migration to new smart plugs necessitated implementing secure direct connections for each device, adding complexity to the deployment and opening security problems using standard settings.

System stability issues emerged from distribution upgrades and varying connectivity options, addressed through automated restart mechanisms. Significant code improvements were required to handle data supply interruptions gracefully while maintaining algorithm functionality.

Control Strategy Implementation: Two switching approaches were implemented and compared: a greedy optimization algorithm for optimal appliance scheduling and a traditional virtual switching scheme. The system addressed distinct control scenarios - electric vehicle charging with energy boundary conditions, and domestic hot water (DHW) heating considering both target temperature timing and prognosed thermal solar energy yield integration in the reasoning. While photovoltaic surplus serves as an additional control trigger, full implementation awaits expanded PV capacity installation.

System Architecture: The control architecture maintains device autonomy by providing binary power control to battery electric vehicle (BEV) chargers, monoblock air conditioning units, and DHW controllers, while implementing direct setpoint control for split-type AC units. This second approach enabled model predictive control strategies leveraging the thermal mass characteristics of the building envelope.

FINDINGS AND OUTLOOK

The pilot demonstrates both the potential and practical challenges of implementing residential flexibility services, providing valuable insights for scaling demand response solutions in distributed energy systems. It also gives answers about the options available for rolling out flexibility services in a decarbonisation scenario for the electricity grid having prognoses' of CO2eq during the day. This information so far is not available, but only dynamic tariffs from EEX AT which are used in the pilot. The second boundary condition apart from CO2, the local grid congestion may be also implemented this way once we have dynamic grid fees.

Climate Risk, Supply Chain Disruption, and Oil Price Uncertainty: The Role of ICT and Technological Innovation in Shaping Food Security in Qatar

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ABSTRACT.

This study examines the dynamic impacts of climate change, supply chain disruption (sch), and oil price uncertainty (opu) on food security in qatar, considering the role of information and communication technologies (ict) and technological innovation (tec) from 2005 to 2024. Estimating over time and quantile dynamic panel, we find that climate risk has a strong negative impact on food security, and this is more significant at the upper rather than lower quantiles of the distribution, as extreme events cause greater vulnerability. Sch also diminishes food security, with the greatest effect being during geopolitical shocks and the recent red sea tension.. Also, the estimated opu exhibits a similarity effect. When oil prices soar, expenses initially increase, leading to weakened food security. However, at high quantiles, the effect diminishes due to adjustment factors within qatar's economy. The results highlight the crucial role of ict adoption and technological innovation in ensuring food security under climate variability, volatile energy prices, and supply chain vulnerabilities.

SOLAR THERMAL SYSTEMS TRAINING AND AWARENESS FOR GENDER & DIVERSITY

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ABSTRACT

The South African National Development Institute (SANEDI) and AEE INTEC under the banner of SOLTRAIN+ is creating awareness on Renewable Energy (RE), and Energy Efficiency (EE), more specifically on capacity building and demonstration of renewable energy systems and energy efficiency in the SADC region.

The awareness training sessions in Gender & Diversity, include basic RE and EE understanding and then focus on how Solar thermal systems works and can make a difference across varying scales. The awareness and training guide the participants through solar energy resources, technologies, applications, and system design. Participants get a chance to engage in both theoretical sessions and practical demonstrations of solar thermal systems. The Soltrain+ G & D targets and aims defined in the project as well as findings of the situational needs assessment performed in the project. Some of the activities in WP5 trigger heat debates showing that the gender mainstreaming topic is a topic that in included in policies of all countries but still needs discussions and change in the mindset to reach the target of inclusive access to possibilities in Renewable Heating and Cooling sector.

The Gender & diversity implementation plans are part of the gender & diversity strategy. The activities are planned individually for each country depending on the focus the country would like to take, as well as the needs identified by the gender managers in line with the gender & diversity project workstream and in response to the situational analysis barriers of lack of awareness to opportunities. The workshops and training aimed to raise awareness about sector, technologies, career path options and provide opportunities to access financial funding (Bursaries). SANEDI started hosting awareness trainings for other government entities, private companies whereby gender & diversity presented. The training was restricted to technical experts and professionals in the solar thermal sector. The training courses are intended for individuals that already have a technical background in energy assessment or energy performance as well as the potential of Solar Thermal Technologies.

need to do their part, re-prioritizing their gender equality initiatives if they have not already. The path forward for solar thermal systems and applications involves scaling up solar sector and encouraging private sector investment through policy changes, investing in battery storage, and implementing programs that will support females/women in the energy sector.

SANEDI in collaboration with Soltrain+ hosted training course on the 2nd & 3rd of June 2025 aiming at conceptualising, planning and implementing renewable heating and cooling solutions within industries and commerce sector. A total of **23 participants** attended the training, including **7 female** and **16 male** participants.

WP5 Presentation and Gender-Specific Challenges in the Energy Sector

As part of the training agenda, **Work Package 5 (WP5)** was presented, with a focused discussion on the challenges faced by women in the energy sector. Participants engaged in a robust dialogue, identifying both systemic and operational barriers. The following challenges were raised:

1. **Inadequate PPE and Field Equipment for Women**
2. **Gender Bias in Performance Perception**
3. **Workplace Culture and Environmental Challenges**
4. **Pressure to Constantly Prove Competence**
5. **Gender Pay Gap**
6. **Sexual Harassment**
7. **Work-Life Balance Struggles**
8. **Gender Stereotyping in Mentorship and Roles**

We still have a mountain to climb regarding balancing the males and females in the energy sector. As the world begins to get back to normal, we believe this is fixable. Companies need to do their part, re-prioritising their gender equality initiatives if they have not already. The path forward for solar thermal systems and applications involves scaling up solar thermal sector and encouraging private sector investment through policy changes and implementing programs that will support females/women in the sector.

This abstract refers to Marketing, dissemination and implementation strategies

MONITORING AND COMPARATIVE ANALYSIS OF FORCED CIRCULATION SOLAR THERMAL INSTALLATIONS PARTIALLY FUNDED BY SOLTRAIN IN THE UNIVERSITY OF BOTSWANA

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SUMMARY

The study presents the monitoring and comparative analysis of forced-circulation solar water heating systems installed in Botswana, with partial funding from the SOLTRAIN project. It aims to identify and document all SOLTRAIN partially funded forced-circulation solar thermal systems across the university, capturing their design specifications, operational settings, and environmental conditions. Real-time operational data—including solar radiation, inlet and outlet temperatures, flow rates, and energy outputs—will be collected using monitoring software and sensors. Standard thermal performance equations will be applied to evaluate efficiency and reliability, while results will be compared against design expectations to highlight gaps in performance. Comparative analysis across different installations will further identify the most effective systems, reveal underperforming ones, and establish best practices for design and operation. The findings will provide evidence-based insights into the effectiveness of current installations, support informed decision-making for maintenance and future projects, and contribute to the university's sustainability strategy.

Keywords: monitoring, forced-circulation, comparative, performance, solar thermal

INTRODUCTION

Across Africa, solar thermal research has sought to address high energy demand and unreliable electricity supply. Studies highlight the role of solar water heating in reducing household and institutional electricity costs. For example, (Oladiran & Ossenburg, 2013) examined the performance of installed solar water heaters in Southern Africa and identified technical challenges such as scaling in pipes and lack of proper maintenance. Other works have shown that many systems fail prematurely due to insufficient monitoring and lack of data-driven evaluation methods. Although these studies provide valuable insight, most were based on short-term field observations or laboratory simulations, with limited long-term operational data. This indicates a methodological gap: while international studies are highly data-driven, regional research often lacks structured monitoring through digital tools, making comparative analysis difficult.

In Botswana, the adoption of solar water heating has been promoted through initiatives such as SOLTRAIN (Southern African Solar Thermal Training and Demonstration Initiative). Demonstration systems at the University of Botswana and surrounding institutions were installed to showcase both thermosyphon and forced-circulation technologies. However, studies reveal that while these systems exist, few comprehensive performance evaluations have been carried out (SOLTRAIN, 2024). Current SOLTRAIN reports highlight that digital monitoring platforms are available, but limited efforts have been made to systematically use this data for performance evaluation and comparative analysis. (Kolobeng, Mooketsi, & Nwaigwe, 2022) conducted a case study designing a pumped forced-circulation solar water heating system for a University of Botswana hostel (Block 413). They measured hot water demand (≈ 2160 L/day), estimated cost savings ($64/year vs. $115/month

conventional cost), and determined that solar energy could provide up to 97.6% of the hot water supply. These regional studies naturally flow in our project's core: they highlight local needs, design considerations, and performance challenges that our monitoring and comparative analysis.
This study is therefore positioned to address these gaps by utilizing existing digital monitoring platforms at the University of Botswana (provided through SOLTRAIN systems) to collect operational data such as inlet/ outlet temperature, flow rate, and solar irradiance, conducting a comparative analysis of the performance of different forced-circulation installations within the university, and linking results to international standards of efficiency evaluation to highlight similarities and differences in system operation.

The abstract shall be two pages long to allow a good understanding of the topic.
You will receive notification of acceptance in November 2025 latest.

STUDY METHODOLOGY

This study will adopt a quantitative analytical and comparative methodology. The first step is to identify and document all forced-circulation solar thermal systems within the University of Botswana. This involves:

- Survey of existing installations: Collecting records, technical drawings and available documentation of each system.
- System Profiling in CMI: Each identified system will be profiled in CMI software, which is capable of creating digital system overviews and linking them with monitoring inputs.
- Centralized Documentation: A database will be created that combines physical system details with their CMI profiles, ensuring that all installations are digitally traceable.

Secondly, since the project does not involve installing new physical sensors, Winsol and CMI software will be used to collect and log real-time data from the systems already connected to monitoring devices.

- Climate Data Input: Meteorological datasets specific to Gaborone, Botswana (including solar radiation, ambient temperature, and wind speed) will be incorporated into Winsol, which allows integration of meteorological conditions with system performance.
- Data Logging: Winsol will continuously record operational parameters such as solar radiation levels, inlet and outlet fluid temperatures, flow rate and pump activity, and energy delivered to storage tanks.
- Data Synchronization: The collected data will be exported to CMI software, where it will be organized and structured for easier retrieval and comparison.

Next, the simulated data will be analyzed to evaluate the performance and efficiency of each system.

- Thermal Performance Calculations: Standard solar thermal equations will be applied, including:
  - Useful heat gain (Qu)

$$Qu = \dot{m} \times Cp \times (Tout - Tin) \qquad \text{(eq.1)}$$

  - Collector efficiency (η):

$$\eta = \frac{Qu}{Ac \times It} \qquad \text{(eq.2)}$$

Where: $\dot{m}$= mass flow rate, C_p= specific heat of fluid, T_{out},T_{in} = outlet and inlet temperatures, A_c= collector area, I_t= incident solar radiation.

- Comparison with design specifications: Actual performance will be compared with the system's design expectations to identify deviations.

- Simulation Validation: SIMULIA visualization tools for example contour plots, fluid flow animations, and temperature distributions will be used to confirm the results and provide deeper insight into system behavior.
- Graphical Analysis: Performance graphs will be generated showing efficiency variation with time, solar radiation and temperature.

Finally, after analyzing the performance of each system, a comparative study will be carried out.

- Ranking systems: Systems will be compared based on key performance indicators such as efficiency, energy savings and consistency.
- Identification of Performance Gaps: Underperforming systems will be examined for potential causes such as poor orientation, shading effects, or mismatches between design and operation.
- Visualization and Reporting: Using the 3DEXPERIENCE platform, comparative dashboards will be created to visualize results side-by-side for easy interpretation.
- Recommendations: Based on the analysis, improvement strategies will be proposed, such as optimizing flow rates, adjusting collector tilt, or enhancing insulation.

REFERENCES

Kolobeng, C., Mooketsi, S., & Nwaigwe, K. N. (2022). Design of a Pumped Solar Water Heating System for a University of Botswana Hostel- A case study.

Oladiran, T.N., & Ossenburg, E. (2013). Evaluation of solar water heating systems in Botswana. Advanced materials Research.

SOLTRAIN. (2024). The Clean Energy Research Centre (CERC), University of Botswana hosts the 8th SOLTRAIN Conference.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers (2.07): SMART SERVICES AND SYSTEM OPERATION

METHANE PYROLYSIS IN LIQUID METALS FOR SUSTAINABLE HYDROGEN PRODUCTION

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SUMMARY

Hydrogen is widely seen as a key element of the energy transition, but current industrial production routes remain carbon intensive. Steam methane reforming (SMR) still dominates the sector due to its low cost, but its large greenhouse gas emissions undermine hydrogen's potential as a clean energy carrier.
Methane pyrolysis provides a CO_2-free pathway by breaking down methane into hydrogen and solid carbon. The main difficulty is overcoming the strong C–H bond of methane, which requires reaction temperatures above 1200 °C. Catalytic systems help lower the activation barrier, enhance methane conversion, and allow operation at reduced energy inputs.
Among various catalytic materials, liquid metals and alloys stand out because they offer a dynamic catalytic environment. Their molten state constantly exposes fresh active surfaces, thus mitigating deactivation from carbon deposition and enabling straightforward separation of the carbon product, as it floats on the melt surface. This combination of catalytic function and favourable reactor operation makes liquid metals highly promising media for sustainable hydrogen production.
Keywords: methane pyrolysis, hydrogen, carbon, molten metal catalysts, decarbonization, energy transition.

INTRODUCTION

Meeting the rapidly growing global demand for hydrogen requires processes that are both economically viable and environmentally friendly (IEA, 2023, 2024). Conventional steam methane reforming (SMR) remains the most used method, accounting for about two-thirds of the 97 Mt of hydrogen produced worldwide in 2023 (IEA, 2024). While its low production cost is beneficial, it results in the emission of nearly 9 kg CO_2 per kg H_2, making large-scale use incompatible with decarbonization goals (IEA, 2023, 2024).
Methane pyrolysis avoids this issue by converting methane into hydrogen and solid carbon in a non-oxidative environment (Al-Qahtani *et al.*, 2021; Patlolla *et al.*, 2023). Since no CO_2 is produced directly, the process provides a cleaner and potentially scalable alternative (Al-Qahtani *et al.*, 2021; Patlolla *et al.*, 2023). However, due to the high stability of methane (Zhao *et al.*, 2022), catalysts can be utilized for lowering activation energies and achieving practical efficiency (Sánchez-Bastardo *et al.*, 2021).
Various catalytic systems have already been investigated in previous works. Carbonaceous catalysts and molten salts offer some activity but face stability and process-integration challenges (Ashik *et al.*, 2015; Sánchez-Bastardo *et al.*, 2020; Patlolla *et al.*, 2023). Metals, on the other hand, show better catalytic performance, yet traditional solid catalysts deactivate quickly due to coking (Sánchez-Bastardo *et al.*, 2020). To overcome this problem, research has increasingly focused on liquid metals and alloys, which combine catalytic activity with unique reactor dynamics and carbon separation advantages (Patlolla *et al.*, 2023).

METHANE PYROLYSIS IN LIQUID METALS

In a liquid-metal bubble column reactor, methane is injected into the lower part of the molten bath, where it forms bubbles that rise through the liquid section, within which pyrolysis takes place (see Fig. 1) (Patlolla *et al.*, 2023; Hofberger *et al.*, 2024). This design guarantees efficient gas-liquid contact, and the solid carbon product floats on the melt, allowing it to be removed to prevent reactor clogging (Patlolla *et al.*, 2023; Hofberger *et al.*, 2024). Besides their catalytic activity, liquid metals significantly influence bubble size, residence time, and surface area through their viscosity and surface tension (Patlolla *et al.*, 2023). These parameters directly affect methane conversion (Palmer *et al.*, 2019).

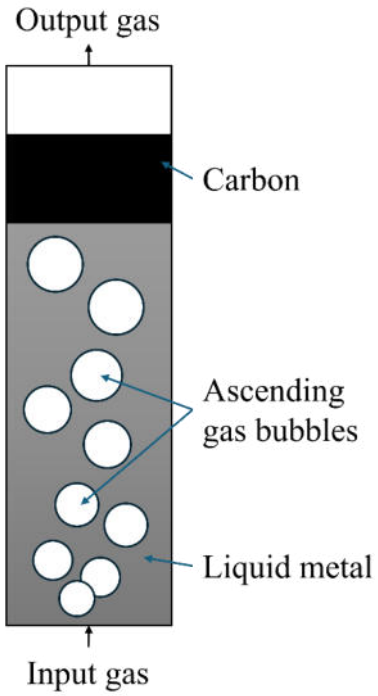


Fig. 1: Schematic representation of a liquid-metal bubble column reactor for methane pyrolysis

Recent experimental studies have demonstrated that different liquid metals and alloys can significantly improve process efficiency. Systems utilizing metals and alloys such as Sn, Cu-Bi, Ni-Bi, and Ni-Te have been tested, showing activation energies around ~160–350 kJ/mol. Comparing these systems highlights the dual importance of alloy chemistry and melt properties: catalytic metals such as Ni reduce activation barriers, while metals with low viscosity and low surface tension, like Sn or Bi, promote gas residence and bubble surface area. The overall conversion depends on the balance of these factors. (Upham *et al.*, 2017; Palmer *et al.*, 2019; Zeng *et al.*, 2020; Zaghloul *et al.*, 2021)

Liquid metals thus offer three main advantages: (i) sustained catalytic activity due to their resistance to coking, (ii) better reactor operation through favorable dynamics, and (iii) easier carbon separation, enabling continuous operation. Additionally, the solid carbon by-product can be a valuable material stream, supporting co-production strategies that enhance the economics of hydrogen production. (Patlolla *et al.*, 2023; Hofberger *et al.*, 2024)

This work is focused on the effects of different alloy compositions. Altering physical and chemical properties as well as recognizing isokinetic regimes, where catalytic and dynamic effects converge, will be key to improving process efficiency. Ultimately, liquid-metal-based methane pyrolysis emerges as a promising option for CO_2-free hydrogen production on a large scale, contributing to global sustainability objectives.

REFERENCES

Al-Qahtani, A., et al., (2021), Uncovering the true cost of hydrogen production routes using life cycle monetisation. Applied Energy 281: 115958.

Ashik, U., et al., (2015), Production of greenhouse gas free hydrogen by thermocatalytic decomposition of methane – A review. Renewable and Sustainable Energy Reviews 44: 221–256.

Hofberger, C., et al., (2024), Technical Aspects of Natural Gas Pyrolysis in Liquid Metal Bubble Column Reactors. Energy Technology 12(9).

IEA, (2023), Towards hydrogen definitions based on their emissions intensity. Paris: IEA.

IEA, (2024), Global Hydrogen Review 2024. Paris.

Palmer, C., et al., (2019), Methane Pyrolysis with a Molten Cu–Bi Alloy Catalyst. ACS Catalysis 9(9): 8337–8345.

Patlolla, S.R., et al., (2023), A review of methane pyrolysis technologies for hydrogen production. Renewable and Sustainable Energy Reviews 181: 113323.

Sánchez-Bastardo, N., et al., (2021), Methane Pyrolysis for Zero-Emission Hydrogen Production: A Potential Bridge Technology from Fossil Fuels to a Renewable and Sustainable Hydrogen Economy. Industrial & Engineering Chemistry Research 60(32): 11855–11881.

Sánchez-Bastardo, N., et al., (2020), Methane Pyrolysis for CO_2-Free H_2 Production: A Green Process to Overcome Renewable Energies Unsteadiness. Chemie Ingenieur Technik 92(10): 1596–1609.

Upham, D.C., et al., (2017), Catalytic molten metals for the direct conversion of methane to hydrogen and separable carbon. Science (New York, N.Y.) 358(6365): 917–921.

Zaghloul, N., et al., (2021), Hydrogen Production by Methane Pyrolysis in a Molten-Metal Bubble Column. Chemical Engineering & Technology 44(11): 1986–1993.

Zeng, J., et al., (2020), Catalytic Methane Pyrolysis with Liquid and Vapor Phase Tellurium. ACS Catalysis 10(15): 8223–8230.

Zhao, J., et al., (2022), Stretching C-H bond in methane by solid frustrated Lewis pairs. Chem Catalysis 2(7): 1521–1523.

CONFERENCE TOPIC

1.11. Net-zero/negative Emissions in the Industry including CCUS

1.12. Next-Generation Technologies for Renewable Energy and Resource Efficiency

TOWARDS CLEAN HYDROGEN PRODUCTION: PILOT-SCALE METHANE PYROLYSIS IN LIQUID METAL CATALYSTS

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SUMMARY

Climate change mitigation requires rapid decarbonization of both energy and industrial sectors. While the Paris Agreement and the EU Green Deal set ambitious climate targets, global hydrogen production remains primarily driven by CO_2-intensive methods, with low-emission pathways accounting for less than 1 %.
Methane pyrolysis offers a promising alternative, splitting methane into hydrogen and solid carbon at significantly lower reaction enthalpy than water electrolysis. Catalytic approaches using molten metal alloys (e.g., CuBi, NiSn, FeSi) enable operation at reduced temperatures and prevent catalyst deactivation. At the Technical University of Leoben, reactor development has advanced from small-scale laboratory systems (2 kg metal) to a fully instrumented pilot plant with pressurized operation (up to 10 bar), gas preheating, flexible injection systems, and interchangeable reactor sizes, creating a platform for process optimization.
Keywords: hydrogen, carbon, methane pyrolysis, molten metal catalysts, pilot plant, decarbonization, energy transition.

INTRODUCTION

The ongoing progression of climate change represents one of the most significant societal challenges of the 21st century. The Paris Agreement established the objective of keeping global warming well below 2 °C compared to pre-industrial levels, with efforts focused on staying below 1,5 °C (United Nations, 2015). According to the World Meteorological Organization (WMO) report on the state of climate change, the temperature increase recorded in 2024 had already reached 1.55 °C (± 0.13 °C) (WMO, 2025). Although a single year might be seen as an outlier, since 2015, every year has been among the hottest on record, indicating a clear trend of rapid warming. In addition to the Paris Agreement, the European Union aims for complete carbon neutrality by 2050 through the European Green Deal (European Commission, 2019).
Meeting these goals requires a fundamental transformation, exemplified by the ongoing energy transition. However, major changes are also necessary in the industrial sector, where many processes are difficult to electrify. Consequently, an alternative to the conventional utilization of natural gas is required. In this context, hydrogen plays a key role, serving both as a combustion fuel and as an essential reducing agent (European Commission, 2019).

TODAY'S HYDROGEN PRODUCTION

Implementing hydrogen in a CO_2-neutral industry and energy system requires production pathways that are free of greenhouse gas emissions. In 2024, global hydrogen generation reached nearly 100 Mt H_2 and is projected to continue growing. The largest percentage, however, still stems from carbon-intensive methods relying on coal or natural gas, such as steam methane reforming. In contrast, low-emission routes account for less than 1 % of the global supply; this includes hydrogen produced with CCUS and hydrogen from electrolysis powerd by renewable energy. Green electrolysis alone constitutes a tiny fraction of production. (IEA, 2025)

METHANE PYROLYSIS

Methane pyrolysis is a process that, at high temperatures and in the absence of oxygen, splits methane (CH_4) into hydrogen and carbon. The reaction (eq. 1) proceeds with a standard reaction enthalpy of 37.4 kJ/mol H_2 endothermically (Msheik *et al.*, 2021) which is comparable to steam methane reforming (41.3 kJ/mol) (Ade *et al.*, 2022; Chen *et al.*, 2023).

$$CH_4 \rightarrow H_2 + C \qquad \text{(eq. 1)}$$

To achieve reasonable hydrogen yields through methane pyrolysis without catalysts, high temperatures (usually above ~1000-1200 °C) are required (Msheik *et al.*, 2021; Chen *et al.*, 2023). Catalysts (e.g., Ni, Fe) enable lower temperature operation, in many cases in the range of 600-900 °C, though catalysts in this regime often suffer from rapid deactivation due to carbon accumulation (coking) on the active surface (Song and Park, 2024). To address this issue, research is increasingly focused on molten metal or molten alloy catalysts. In these systems, the solid carbon product precipitates and floats on top of the liquid medium due to the density difference, allowing for easy removal. In a liquid metal pyrolysis system, process parameters such as alloy composition, temperature, bubble size, melt viscosity, surface tension, and methane residence time are key determinants of the overall efficiency, stability, and hydrogen yield (Upham *et al.*, 2017; Moghaddam *et al.*, 2025).

PATH TO THE PILOT PLANT

Since 2020, the Technical University of Leoben has been developing methane pyrolysis processes using liquid metal reactors across multiple scales. Initial experiments utilized alloy systems such as CuBi, NiSn, and FeSi in a laboratory reactor containing approximately 2 kg of molten metal. Methane was introduced through an Al_2O_3 lance, and carbon was separated from the product gas via a ceramic hot-gas filter. Subsequent scale-ups included a 20–25 kg reactor with a similar process design and a second 25 kg system equipped with gas preheating and bottom gas injection to improve process efficiency.

As the final step in scale-up, a pilot plant was constructed to enable operation under conditions relevant to industry. The main feature of this plant is an induction furnace installed in a pressurized vessel capable of handling up to 10 bar. It offers both lance and bottom gas injection options, as well as interchangeable reactor units with varying diameters (150–300 mm) and fill heights (600–1000 mm), enabling flexible operation. Carbon separation is achieved with a hot-gas filter. This pilot setup enables the early identification of process challenges and a systematic investigation of optimal operating parameters, such as temperature, pressure, and feed gas flow rate, thereby speeding up industrial implementation.

REFERENCES

Ade, N., et al., (2022), Integrating safety and economics in designing a steam methane reforming process. International Journal of Hydrogen Energy 47(9): 6404–6414.

Chen, L., et al., (2023), Ternary NiMo-Bi liquid alloy catalyst for efficient hydrogen production from methane pyrolysis. Science (New York, N.Y.) 381(6660): 857–861.

European Commission, (2019), The European Green Deal. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0640.

IEA, (2025), Global Hydrogen Review 2025. https://www.iea.org/reports/global-hydrogen-review-2025.

Moghaddam, A.L., et al., (2025), Methane pyrolysis for hydrogen production: navigating the path to a net zero future. Energy & Environmental Science 18(6): 2747–2790.

Msheik, M., et al., (2021), Methane Cracking for Hydrogen Production: A Review of Catalytic and Molten Media Pyrolysis. Energies 14(11): 3107.
Song, J. and Park, S., (2024), Review of methane pyrolysis for clean turquoise hydrogen production. Journal of Analytical and Applied Pyrolysis 183: 106727.
United Nations, (2015), The Paris Agreement. https://unfccc.int/process-and-meetings/the-paris-agreement.
Upham, D.C., et al., (2017), Catalytic molten metals for the direct conversion of methane to hydrogen and separable carbon. Science (New York, N.Y.) 358(6365): 917–921.
WMO, (2025), State of Global Climate Change 2024. https://library.wmo.int/idurl/4/69455.

CONFERENCE TOPIC

1.11. Net-zero/negative Emissions in the Industry including CCUS
1.12. Next-Generation Technologies for Renewable Energy and Resource Efficiency

LOAD OPTIMIZATION FOR BOREFIELDS

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SUMMARY

Borehole heat exchangers (BHEs) combined with heat pumps provide a low carbon solution for heating and cooling in buildings. Long-term performance is significantly influenced by how thermal loads are managed during operation. Unfavorable load distributions can result in gradual ground temperature changes, reducing efficiency and potentially violating environmental regulations. This paper describes a method for determining an optimal load curve, which serves as a theoretical upper limit for sustainable energy exchange within a borefield. The curve is determined based on site-specific thermal properties of the ground, borefield geometry, and g-function response models. It identifies the maximum allowable load according to heat extraction or injection rates, enabling operators to evaluate actual operations in relation to the recommended operating limits. By considering site-specific factors such as the number, length, and arrangement of boreholes, as well as geological and hydrogeological characteristics, this method supports adaptive management strategies that aim to optimize efficiency while maintaining subsurface resources. The optimal load curve functions as both a planning reference and an operational benchmark, supporting sustainable geothermal heat utilization in integrated energy systems.

INTRODUCTION

Borehole heat exchangers (BHEs) in combination with heat pumps are now widely adopted for delivering low-carbon solutions for heating and cooling in buildings. Despite their technical maturity, the long-term performance of BHE systems is not guaranteed by design alone. The underground environment reacts gradually to thermal changes, and unbalanced heat extraction or injection across multiple seasons can cause persistent temperature shifts that accumulate over time. This may lead to regulatory environmental violations. Operation strategies therefore play a central role in ensuring that the ground is used sustainably. Currently, most borefield capacities are communicated as static figures such as W per metre of borehole length. These simplifications ignore the temporal dynamics of heat transfer and provide no guidance for balancing short term load peaks with long term sustainability.

CONCEPT OF THE OPTIMAL LOAD CURVE

The optimal load curve concept, models the energy transfer potential of borefields as a time-dependent function rather than a fixed value. G-functions simulate ground thermal response under heat loads, enabling determination of maximum sustainable loads when scaled by the allowable borewall temperature limits. Short-term operations can handle higher loads because the ground initially absorbs or releases heat effectively, while longer operations require lower loads as the ground's ability to transfer heat becomes more relevant. This methodology provides a method for establishing load limits across temporal scales within specified thermal boundaries.
BHE fields vary widely in terms of borehole number, depth, spatial configuration, and probe design. Crucially, subsurface geological characteristics such as thermal conductivity or volumetric heat capacity significantly affect heat transport and determine the efficiency and resilience of the system. To get the best performance and utilize the underground sustainably, adaptive management should consider all these factors when creating optimal load

curve. The calculation of the optimal load curve starts with collecting relevant geological and technical data to characterize the site. This is followed by calculating g-functions to model the thermal behavior of the borefield. To derive the optimal load curve, a Mixed-Integer Linear Programming (MILP) approach is applied. This method enables the optimization of the load curve while respecting thermal boundaries and operational constraints. It also allows for the incorporation of seasonal heating and cooling demands, ensuring that the system remains flexible and efficient under varying conditions.
The optimal load curve serves as a benchmark rather than a rigid schedule. Comparing actual extraction and injection profiles against these theoretical limits provides a clear measure of proximity to safe operating conditions. Loads below the curve indicate underutilization, while approaching or exceeding the curve signals the need for corrective action or at least caution. This enables seamless integration of real-time monitoring into adaptive control schemes such as adjusting heat pump set-points or scheduling thermal regeneration during periods of low demand.

Improved borefield management greatly benefits operators by providing a clear reference point and establishing a theoretical storage ceiling for geothermal energy use. With the optimal load curve serving as a dynamic benchmark, operators can directly compare real-time system performance against scientifically modeled thresholds, ensuring that extraction and injection activities remain within safe thermal limits. This reference empowers operators to make informed decisions, proactively preventing issues before they escalate. The defined storage ceiling also helps operators understand the maximum sustainable energy exchange their system can support, guiding day-to-day management and long-term planning. By integrating continuous monitoring, predictive modeling, and MILP-based optimization, operators gain actionable insights to adjust set-points or schedule regeneration, all while maximizing efficiency and maintaining system resilience. Ultimately, having a reliable operational reference and theoretical ceiling enhances risk mitigation and secures the geothermal system's role as a dependable, sustainable energy source for heating and cooling.

CONCLUSIONS

This paper proposes a new way of characterizing and managing the capacity of borefields. The optimal load curve captures the time-dependent interplay between applied loads, borefield geometry and subsurface properties, translating complex thermal dynamics into a simple operational benchmark. By accounting for site-specific differences and connecting design parameters to a dynamic capacity profile, it offers planners a robust metric for comparing installations and empowers operators with actionable information for day-to-day management. Integrating the curve into broader energy system optimization frameworks further enhances the value of geothermal energy as a reliable, sustainable heat source.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
"Digitalization for Smart, Resilient Energy Systems "

GOVERNANCE, FINANCING, AND DIGITALISATION TO REDUCE NON-REVENUE WATER (NRW): ADOPTION AND STRATEGIES (CASE STUDY: JAKARTA)

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SUMMARY

Indonesia's non-revenue water (NRW) remains above policy expectations, constraining reliability, equity, and utility finances. We conduct an early-stage, single-case mixed-methods study in Jakarta, using CFIR to examine how governance, financing, and digitalisation are adopted and sequenced within the capital's water utility. Preliminary scoping indicates uneven adoption and persistent gaps between device roll-outs and information governance, risking that initial performance gains dissipate without tariff realism, leadership routines, and data stewardship. We propose that phased, equity-aware cost recovery and disciplined governance should precede scaled digitalisation, enabling credible verification and durable NRW reduction while protecting social objectives.

INTRODUCTION

National NRW averaged 33.5% in 2023, well above the 25% target in the RPJMN 2025–2029, signalling structural frictions in accountability routines, tariff sufficiency, and data stewardship (Ditjen Cipta Karya, 2025). Device roll-outs (DMA/AMI/SCADA) have outpaced information governance in many utilities, eroding the durability of short-run leakage reductions. Jakarta offers a high-learning context to trace how governance reforms (clear mandates, SOP discipline, leadership KPIs), financing pathways (tariff design, phased cost recovery, PPP/PBC readiness), and digitalisation (DMA hygiene, AMI reliability, cyber-hardening, metadata) co-evolve under political and organisational constraints (Tien and Setiono, 2025). Anchored to national benchmarks (Fig. 1), this study seeks to establish a robust adoption baseline and sequencing logic that can inform replicable pathways. The Jakarta case can clarify how to align equity goals with financial viability and data-driven operations by illuminating where operational erosion occurs and which safeguards matter. The resulting framing guides a pragmatic research design focused on implementable levers rather than technology-first fixes.

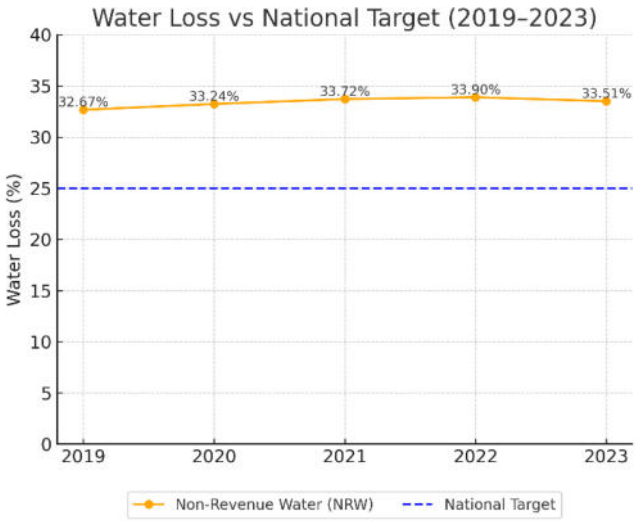


Fig 52. Average National Non-Revenue Water (NRW) Value for Fiscal Years 2019-2023 (Ditjen Cipta Karya, 2025)

METHODOLOGY

We assemble evidence from national benchmarking, Jakarta utility/provincial artefacts (SOPs, dashboards, data dictionaries), and semi-structured interviews with managers and field teams. Analysis proceeds in two layers: (i) CFIR-based coding across intervention characteristics, outer/inner setting, characteristics of individuals, and process (Damschroder *et al.*, 2022); and (ii) a within-case Adoption Profile for each pillar—governance (NRW units, routines, leadership KPIs), financing (tariff sufficiency, PPP/PBC readiness), and digitalisation (DMA hygiene, AMI/SCADA deployment, data stewardship). Sequencing hypotheses (e.g., "data governance before devices") are examined via triangulation and member checks. A concise, compact view of the approach is summarised in Table 1.

Table 2: Methodology Overview

Design Element	Data & Analysis
Design & Cases	Single-case (Jakarta); purposive sampling by size, FCR status, digital readiness
Data	Benchmarks & policy files; Jakarta SOPs/dashboards; interviews
Framework	CFIR coding → within-case synthesis
Outputs	Within-case Adoption Profile + sequencing pattern (governance → finance → digital)

RESULTS

The study is in progress. Anticipated analyses focus on: (i) measuring adoption levels across governance–financing–digitalisation within the Jakarta utility; (ii) identifying enablers and barriers using CFIR (intervention characteristics, outer setting, inner setting, characteristics of individuals, process), with attention to tariff politics, mandate fragmentation, leadership routines, and data stewardship; and (iii) formulating alternative/hybrid strategies that are cost-effective and replicable—community leak-reporting, mass meter-replacement campaigns, social-tariff safeguards tied to incremental cost recovery, and anti-tampering with transparent verification. Final quantified findings will be presented in the final paper.

FUTURE RESEARCH

As an early Indonesian implementation study, our main contribution is scoping: clarifying adoption baselines, surfacing sequencing dependencies, and assembling a feasible strategy bundle tailored to Jakarta's institutional conditions. Future work includes cross-utility benchmarking, indicator governance (definitions, verification,

transparency), and appraisal of financing pathways (PPP/PBC) under equity constraints—toward durable, replicable NRW reduction in Indonesia.

REFERENCES

Damschroder, L.J., Reardon, C.M., Opra Widerquist, M.A. and Lowery, J. (2022), "Conceptualizing outcomes for use with the Consolidated Framework for Implementation Research (CFIR): the CFIR Outcomes Addendum", *Implementation Science*, Vol. 17 No. 1, p. 7, doi: 10.1186/s13012-021-01181-5.

Ditjen Cipta Karya. (2025), *Kinerja BUMD Air Minum Tahun 2024*, Kementerian Pekerjaan Umum, Jakarta, Indonesia, p. 207.

Tien, M. and Setiono, I.M. (2025), "3 Steps to the Sustainable Reduction of Non-Revenue Water in Indonesia | Infrastructure Asia", available at: http://www.infrastructureasia.org/Insights/3-Steps-to-the-Sustainable-Reduction-of-Non-Revenue-Water-in-Indonesia (accessed 17 August 2025).

CONFERENCE TOPIC

Mandatory: Financing and Business Models
Optional: Building the Future: Smart Energy Infrastructure for the Energy Transition

A HYBRID LLM-ENABLED SIMULATION FRAMEWORK FOR CLIMATE CHANGE NEGOTIATIONS: A CASE STUDY OF LIKE-MINDED DEVELOPING COUNTRIES (LMDC)

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SUMMARY

This paper introduces a hybrid simulation framework that uses a Large Language Model (LLM) fine-tuned on the negotiation positions of the Like-Minded Developing Countries (LMDC) to simulate climate diplomacy. The framework integrates the LLM's qualitative outputs with a quantitative energy systems model in a feedback loop. This approach overcomes the limitations of existing aggregated models by capturing the nuanced, text-based arguments of a major negotiating bloc, thereby linking diplomatic rhetoric to tangible energy policy outcomes. It offers a new tool for analyzing the complex interplay of politics and technology in achieving a sustainable energy future.

Keywords: LLM, climate change, climate negotiation, energy system, sustainable energy, LMDC, simulation, policy analysis, diplomacy.

INTRODUCTION

This paper presents a novel hybrid simulation framework that integrates the qualitative strengths of Large Language Models (LLMs) with the quantitative rigor of a simplified energy systems model to analyze international climate negotiations. While existing climate policy simulators, such as C-ROADS, have proven effective for rapid, high-level policy projections, their aggregated, top-down design inherently limits their ability to capture the nuanced, text-based dynamics of diplomacy and the heterogeneity of national and regional circumstances. This research addresses this critical gap by proposing a new class of computational tools that can model not only the physical outcomes of a policy but also the complex, qualitative process of its creation.

The proposed framework is built upon a continuous, multi-stage feedback loop. First, a foundational LLM is fine-tuned on a rich, domain-specific corpus of diplomatic texts, such as the official submissions of the Like-Minded Developing Countries (LMDC) group to the UN Framework Convention on Climate Change (UNFCCC). This process transforms the general-purpose LLM into a specialized negotiating agent that can accurately reproduce the LMDC's core principles and rhetorical style, including its emphasis on historical responsibility, the right to development, and the need for fair, predictable climate finance.

Second, the qualitative, text-based policy proposals generated by this LLM agent are programmatically translated into quantifiable inputs for a simplified energy systems model. This model, focused on the LMDC region, simulates the physical and economic consequences of the proposed policies, tracking key metrics such as emissions trajectories and grid stability. The quantitative results from this simulation are then fed back to the LLM, informing its subsequent rounds of negotiation. This iterative process forces the LLM's diplomatic rhetoric to be disciplined by the practical, on-the-ground constraints of the energy system, thereby creating a more realistic and comprehensive simulation of the policy-making process.

The LMDC group is selected as a case study due to its well-documented and consistent negotiation positions, which provide a robust dataset for training and validation. The paper will demonstrate the framework's utility by simulating three key scenarios: a "just transition" dialogue between the LMDC and a developed country bloc, the LMDC's response to a unilateral trade measure, and a negotiation concerning the terms of climate finance. The analysis will focus on both the quantitative results (e.g., emissions reductions) and the qualitative data (e.g., the language and arguments used by the LLM agent).

This research is highly relevant to the International Sustainable Energy Conference (ISEC) 2026, which focuses on "Research and Innovation in Energy Transition" and the specific challenges of the Global South. By providing a new methodological tool for analyzing the political dimensions of energy policy, this paper contributes to the fields of computational social science, climate policy, and energy systems modeling. It bridges the gap between the "soft" science of diplomacy and the "hard" science of energy, offering a powerful new instrument for researchers, policymakers, and educators seeking to better understand the complex interdependencies of technology, politics, and sustainability.

TABLES

Table 1: Comparative Analysis of Climate Policy Simulation Paradigms (Energy Models Typology)

	Model	Approach		Methdology				
		Top-down	Bottom-up	Hybrid	Econ equilibrium	Optimised	Simulation	Toolbox
1	ABMs			√			√	
2	AIM	√					√	
3	ASF	√				√		
4	C-ROADS	√					√	
5	IAMs	√			√			
6	IMAGE/TIMER	√					√	
7	LEAP		√				√	
8	MARIA	√				√		
9	MARKAL		√			√		
10	MESSAGE		√			√		
11	MiniCAM	√			√			
12	PowerPlan		√				√	
13	RETScreen		√					√
14	SGM	√				√		
15	WEM	√			√			

Table 2: Simulated Policy Scenarios and Key Outputs.

Scenario	Expected Quantitative Outputs	Expected Qualitative Outputs
Scenario 1 – (JTD): Simulating Just Transition Dialogue	Emissions trajectory for the LMDC region over time.	The LLM agent's output is expected to be diplomatic dialogue and policy proposals that consistently reference the LMDC's core principles, such as historical responsibility, equity, and the right to development.
	Energy mix composition for the LMDC region over time (e.g., percentage of fossil fuels, renewables).	Arguments for a "diversified energy mix, including fossil fuels" and for respecting "national circumstances and capacities".
Scenario 2 – (IUM): The Impact of Unilateral Measures	Simulated negative impacts on the LMDC region's economy and industries.	A formal statement from the LMDC agent vocally opposing the unilateral measure, such as a Carbon Border Adjustment Mechanism (CBAM).
	Data on financial flows and the economic cost of the trade measures.	The LMDC agent is expected to demand "grant-based financial support" to remediate the negative impacts and to reject any measure that "penalize their industries".

Scenario 3 – (RCF): The Role of Climate Finance	Financial flows for a specific energy project (e.g., breakdown of public vs. private finance).	The LLM agent's response is expected to align with the LMDC's documented position of rejecting "blended finance" and "crowding in private finance".
	Project implementation rate and its impact on the LMDC's debt.	The LMDC agent will consistently argue for predictable, grant-based public finance with no conditionalities.

FIGURES

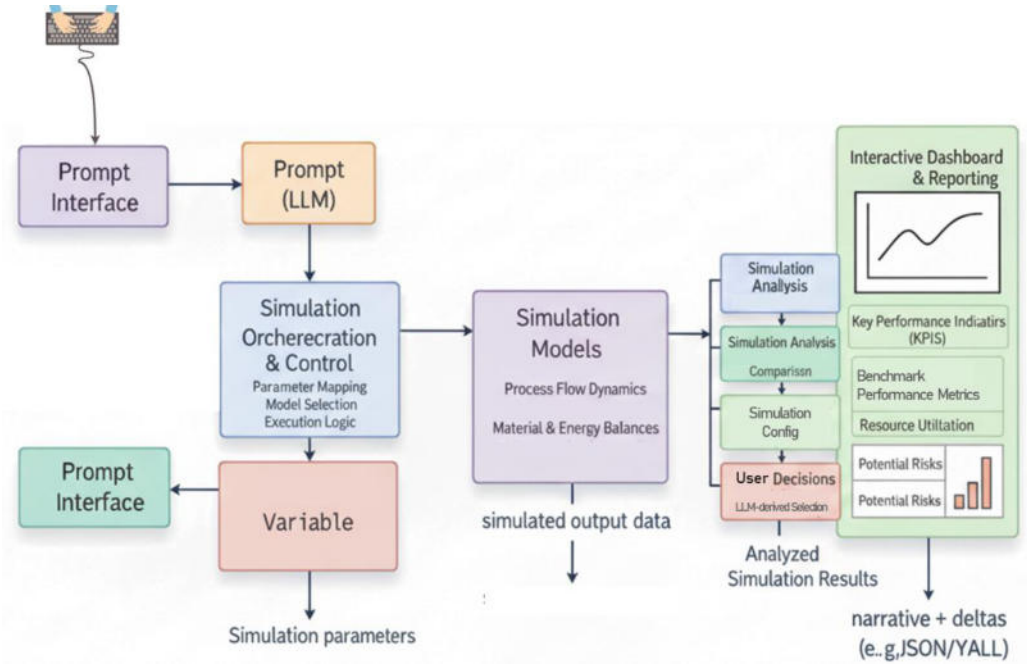


Figure 1: The Hybrid LLM-Enabled Simulation Framework.

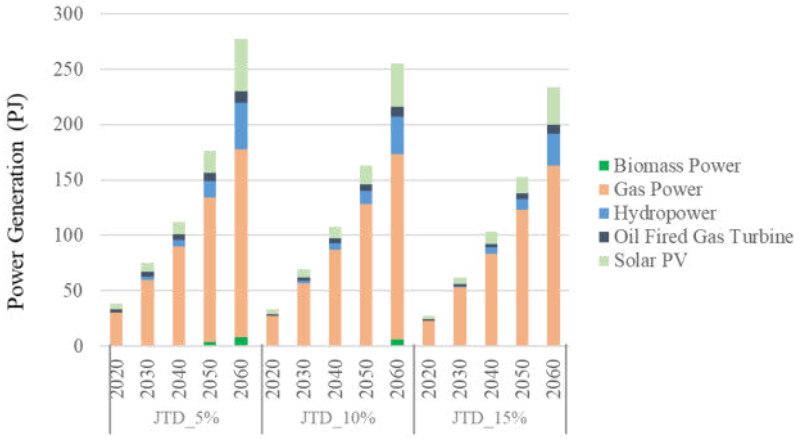


Figure 2: LMDC Energy Mix under JTD Scenario Comparisons.

CONFERENCE TOPIC

2.02. IT Solutions and Artificial Intelligence
1.05. Digitalization for Smart, Resilient Energy Systems
2.03. Just and inclusive mechanism for the energy transition

LOW TEMPERATURE DISTRIBUTED DHC PLANT FOR RESIDENTIAL COMMUNITIES

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SUMMARY

Energy communities (ECs) represent a collective and decentralised energy systems that exploit local and renewable resources for generation and consumption. In this respect, ECs play a relevant role in the fulfilment of decarbonization targets. Despite the concept of energy community has been associated to the electrical carrier, the main effort in terms of sector decarbonization is represented by the thermal one. Thermal sector (i.e., heating and cooling production) represents 50% of the total energy consumption. Hence, the ability in face the decarbonization of thermal sector appears the most promising action to get the fixed targets. This paper proposes a low temperature district heating and cooling (DHC) system exploiting geothermal and photovoltaic sources [1]. The DHC system has a decentralized architecture, composed of a main generation unit and several substations. The DHC system is modelled by Simscape and the model of the buildings is designed according to an actual neighbourhood in Turin (Italy). The model of the buildings provides the thermal energy storage capacity and the profiles of consumptions of electricity and heating according to several category of users. The paper also shows the ability in providing flexibility to the energy and flexibility markets.

INTRODUCTION

The 5th generation DHC plant

The 5th generation district heating system is operated at low temperatures, with a decentralized system architecture designed to serve six districts for heating and cooling services.

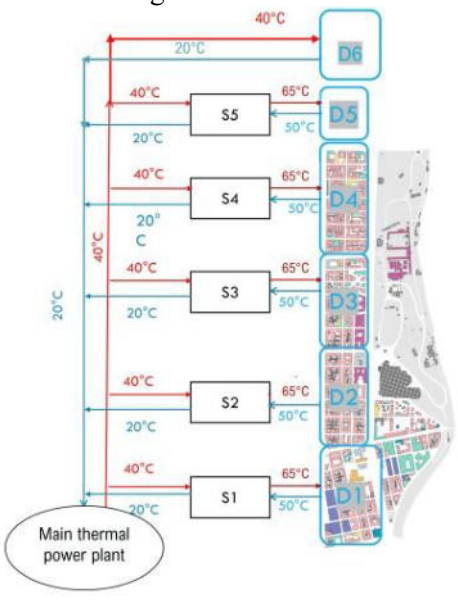


Figure 53 - District heating and cooling system and main network (from [1]).

In detail, the DHC system features include a main thermal power unit consisting of a groundwater source heat pump (GWHP) that supplies thermal power to 6 districts through a main network. The inlet temperature of the GWHP is 20°C, it is supposed the geothermal source is between 150-200*m* and the boreholes of source and discharge do not interact each other. Six substations are connected to the main network, and each one is endowed with a couple of (local) heat pumps to supply the demand of the specific associated district, through a suitable local distribution grid. The inlet and outlet temperatures of the main network are 40°C and 20°C, respectively. The local distribution grids are operated in twofold way according to the radiant system of the buildings. The buildings equipped with traditional radiators are connected to the local distribution grid operated between 63°C and 50°C, while most recent radiant systems (radiant floors for residential and radiant ceilings for offices) are directly connected to the main grid (i.e., 40°C - 20°C).

[14] I. Abbà carried on this activity during her Ph.D. in Politecnico di Torino; Turin Italy.

To complete the description of the plant, a photovoltaic field is supposed to electrically supply the HPs of the DHC system.

Characterization of the thermal demand

The demand was defined according to the structure and the composition of an actual neighbourhood in Turin, named *San Salvario*, and the buildings were characterized in terms of heating and cooling request profiles and electrical consumption. To model the thermal characteristics of the buildings, the Reference Building (RB) approach was used. The concept of Reference Buildings was introduced by the European Directive 2010/31/EU [2], better known as the EPBD recast of 2010, where Member States are required to create RBs to establish a benchmark for buildings that are representative of a portion of the national building stock, to be compared with real buildings in terms of optimal energy performance levels. Reference Buildings are buildings characterized by their functionality and geographical location, including internal and external climatic conditions, and are representative of these characteristic [2] [3]. For the current application, the residential buildings portfolio was categorized into three classes: Single Family House (SFH), Multi-Family House (MFH), and Terrace House (TH), across three construction periods: pre-1980, 1981-2000, and post-2001 [4] [5] [6]. For commercial buildings, a medium dimension office was selected as archetype, and five construction periods were considered (pre-1991, 1992-2005, 2006-2010, 2011-2015, and post-2016). The thermal demand was subdivided into 6 districts, identified by D1-6 labels. Each one of these districts is supplied by the heat pumps held in the suitable substation for the first five districts (D1-5). In these districts the temperature to supply heating power is raised on to 63°C, to be compatible with the operating temperature for radiators and fan coils. The maximum amount of thermal energy in each of the 6 districts is defined as follows: D1 = 1.6 MW, D2 = 1.8 MW, D3 = 2.1 MW, D4 = 1.9 MW, D5 = 2.4 MW, D6 = 2.3 MW. According to the maximum flowrate in each pipeline the size of the pipes was defined.

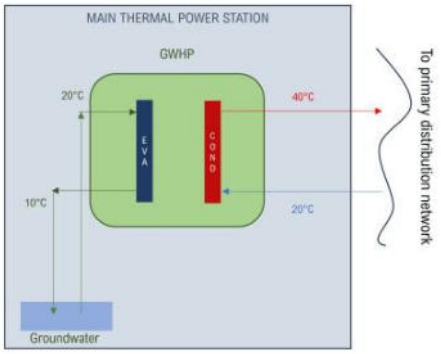


Figure 54 – The ground water heat pump in the main unit connected to the groundwater source and the primary distribution network (from [1]).

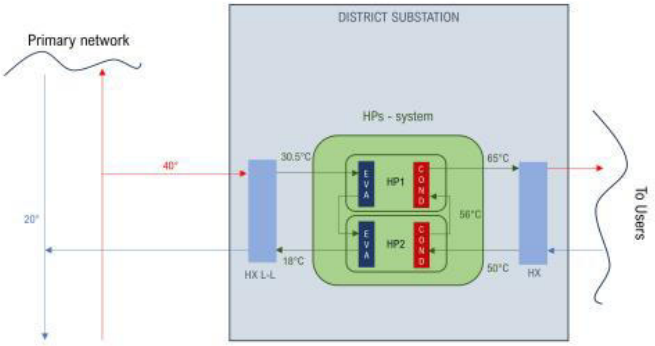


Figure 55 – HP-system held in a district substation, the couple of HPs are connected in series for winter configuration. HP-system is connected to the primary network and users through heat exchangers (from [1]).

An overview of the model set up

For each HP, the thermal power ($Q_{h,cond}$) required by the condenser to guarantee the set-point temperature ($T_{o,cond,SP}$) is calculated as follows:

$$Q_{h,cond} = \dot{m}_{cond}(H_{o,cond,SP} - H_{i,cond}) \quad (1)$$

Where, $H_{o,cond,SP}$ and $H_{i,cond}$ are the input and output enthalpies. Consequently, the electrical consumption of the GWHP is calculated:

$$Q_{e,n} = \frac{Q_{h,n}}{COP_n} \quad (2)$$

Because of the principle of conservation of energy, the thermal power withdrawn at the evaporator is computed.

$$Q_{h,n} = \dot{m}_{cond}(H_{o,cond,SP} - H_{i,cond}) \quad (3)$$

The temperature at the outlet of the condenser is calculated by suitable tables of fluid properties. Then also the electrical power absorbed, and the evaporator thermal power are determined.

$$Q_{h,eva,n} = Q_{h,n} - Q_{e,n} \quad (4)$$

Heat exchanger ideal model consists in a block governed by energy, mass and momentum conservation equations.

$$Q_d = \dot{m}_A c_p (T_A - T_B) \quad (5.1)$$
$$\dot{m}_A + \dot{m}_B = 0 \quad (5.2)$$
$$\phi_A + \phi_B + Q_d = 0 \quad (5.3)$$
$$p_A + p_B + k_{HX} + \dot{m}_A^2 = 0 \quad (5.4)$$

Where: A and B are the inlet and outlet port of the block that simulate the behaviour of the HP, *d*: district, Q_d: thermal power provided to the district [kW], cp: water specific heat [kJ/(kgK)], T_A: water temperatures of the inlet flowrate [K], T_B: water temperatures of the inlet flowrate [K], ϕ_A, ϕ_B: energy flow rates, entering the A port and exiting the B port [kW], $\dot{m}$: water mass flow rate [kg/s], p: water pressures [Pa]; k_{HX} : pressure loss coefficient for heat exchangers.
The daily baseline during the typical winter period for the 6 local heat pumps is depicted in the next figure.

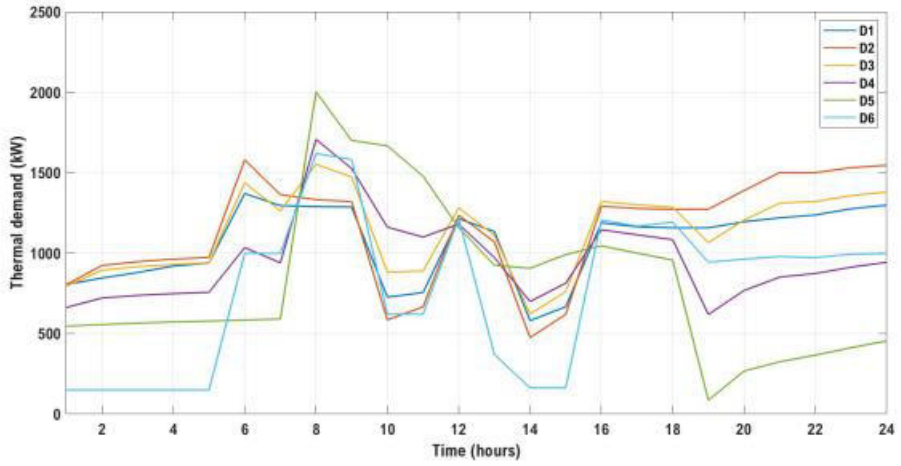


Figure 56 – Profiles of the 6 district demands, supplied by the DHC plant.

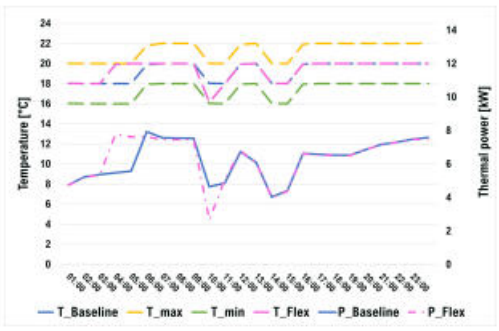
The provision of flexibility by the system

The flexibility provision by the DHC system refers to the intraday market or to the local flexibility market organized by the (electrical) Distributor System Operator (DSO) to face congestion management issues. The DHC system can exploit two different strategies:

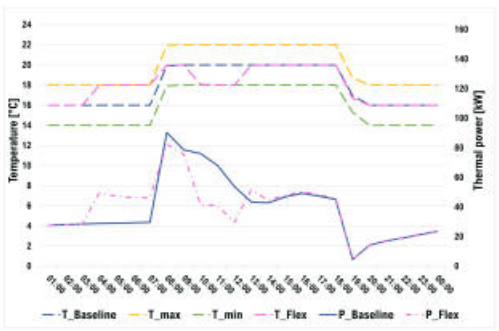
S-1. This strategy exploits the early morning peak shaving. The DHC, through demand-side management actions, anticipates the heating provision, with respect to the baseline, and tries to exploit the convenient energy prices on the intraday market (IDM).
S-2. The photovoltaic plant supplying the district heating system can help in switching to serve the heat pumps with renewable electricity. In this case, the heat pumps modify the absorption profile from the grid in combination with the PV production to provide the committed flexibility.

Application of S-1

In S-1 the thermal storage of building is exploited in order to be able to modulate the operation of the heat pumps in modifying the baseline to increase/decrease the electricity consumption in coherence with the accepted bids on the IDM.



(a) upper (yellow) and lower (green) bounds of the comfort temperature limits for Residential Building. Heat pumps modify the original program (red dashed) as represented by blue line, to face the IDM bids.

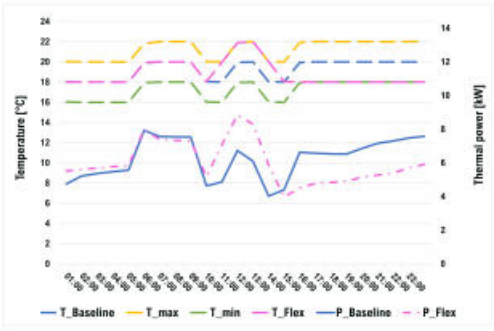


(b) upper (yellow) and lower (green) bounds of the comfort temperature limits for Offices during working days. Heat pumps modify the original program (red dashed) as represented by blue line, to face the IDM bids

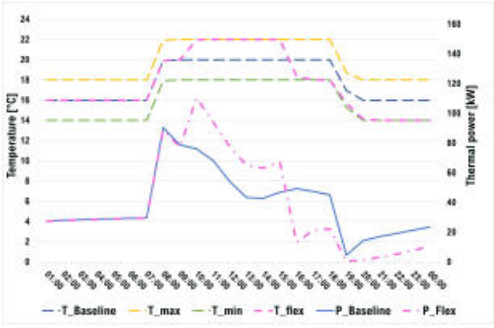
Figure 57 – Temperatures, thermal and electrical power profiles in S-1.

Application of S-2

S-2 is applied adopting the same baseline as the one of S-1. In this case DHC plant provides flexibility for DSO needs exploiting the PV production and the thermal storage of the buildings.



(a) – upper (yellow) and lower (green) bounds of the comfort temperature limits for Residential Building. Heat pumps modify the original program (red dashed) as represented by blue line, to face the IDM bids.



(b) - upper (yellow) and lower (green) bounds of the comfort temperature limits for Offices during working days. Heat pumps modify the original program (red dashed) as represented by blue line, to face the IDM bids.

Figure 58 - Temperatures, thermal and electrical power profiles in S-2.

REFERENCES

[1] I. Abbà, Multi-Vector Energy Integrated Networks for Local Energy Systems, PhD Thesis, Torino: Politecnico di Torino, 2025.

[2] European Parliament, «Directive 2010/31/eu of the european,» 2010/31/eu, 2010.

[3] P. Corgnati, E. Fabrizio, M. Filippi e V. Monetti, «Livelli di prestazione energetica ottimali per edifi ci a energia quasi zero: creazione degli edifici di riferimento,» Atti di convegno, In Italian, 2012.

[4] I. Abbà, G. Crespi, G. Vergerio, C. Becchio e P. Corgnati, «Key perfor-,» *Energies,* 17(3):559 2024.

[5] G. Crespi e E. Bompard, «Drivers for energy transition of italian residential sector,» REHVA, Journal, 57(1):6–11, 2020.

[6] E. Bompard, A. Botterud, P. Corgnati, P. Leone, S. Mauro, G. Montesano, C. Papa, F. Profumo, D. Grosso e T. Huang, «Electrify italy,» Conference, 2020.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

1.13 - Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

ADSORPTION HEAT STORAGE SYSTEMS FOR THE INDUSTRIAL DECARBONIZATION

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SUMMARY

The decarbonization of industrial heat supply requires storage technologies beyond conventional water tanks, which are limited to ~80 °C. Sorption-based heat storage offers higher density, negligible self-discharge, and the ability to deliver process heat above 100 °C. Within the German project *Adsorptive Heat Storage Systems for the Industrial Heat Transition*, systematic lab-scale tests were performed using binder-free zeolite NaY. Inlet temperatures from 50–90 °C at constant 50 mbar water vapor partial pressure enabled temperature lifts up to 100 K, with outlet temperatures exceeding 140 °C. Under these conditions, a corresponding energy density of 145 kWh/m³ was measured. In addition, investigations into long-term functionality under hydrothermal cycling were carried out, using NaX as a reference material. While NaX showed a gradual capacity decline of ~25 %, NaY maintained nearly constant performance. This superior hydrothermal stability highlights NaY as a robust adsorbent for advanced thermal energy storage. **Keywords:** Adsorption Heat Storage Systems, Industrial Decarbonization, Zeolite, Hydrothermal Stability, Energy Density.

INTRODUCTION

The transformation of industrial heat supply requires storage technologies that go beyond the capabilities of conventional water-based systems. Sensible storage systems such as water tanks are limited to operating temperatures of about 80 °C, since physical and safety constraints arise beyond this range. Many industrial processes, however, demand significantly higher thermal levels. Sorption-based heat storage systems offer distinct advantages over conventional water storage. In contrast to sensible storage, they enable significantly higher storage density, loss-free long-term operation without self-discharge, and under suitable operating conditions, in particular elevated inlet temperature and adjusted water vapor partial pressure, the provision of process heat at considerably higher temperature levels. This makes them especially attractive for industrial applications requiring elevated discharge temperatures.

This study is part of the German research project Adsorptive Heat Storage Systems for the Industrial Heat Transition. The aim of the project is to investigate the suitability of zeolite-based storage systems for providing outlet temperatures above 100 °C. Systematic experiments were conducted on a laboratory-scale reactor using binder-free zeolite NaY. The inlet air temperature was varied stepwise from 50 to 90 °C at a constant water vapor partial pressure of 50 mbar. Figure 1 shows the resulting time profiles of temperatures (T_{in} and T_{out} in °C) and absolute humidity (x_{in} and x_{out} in $g \cdot kg^{-1}$) during adsorption. The outlet temperature increased markedly with rising inlet temperature and exceeded 160 °C, corresponding to temperature lifts of up to ~100 K. At higher inlet temperatures the lift decreased slightly, while steeper breakthrough curves indicated reduced water uptake. These findings demonstrate that the high adsorption enthalpy of zeolite NaY enables significant temperature lifts even at moderately elevated water vapor partial pressures, confirming its suitability for a wide range of industrial applications.

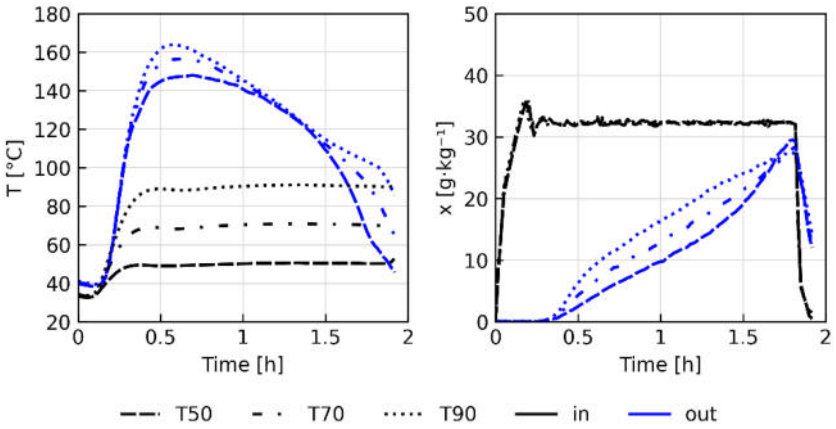


Fig1. Temperature and absolute humidity profiles of NaY at varying inlet temperatures

These findings confirm the fundamental potential of sorptive heat storage systems for high-temperature applications and highlight their relevance particularly in cases where conventional water-based storage reaches its temperature limits.

A critical aspect, however, is the long-term stability of the adsorbent material. Therefore, the hydrothermal durability of NaY was systematically investigated under cyclic exposure to humid hot air. For comparison, NaX was also tested under identical conditions. Two complementary methods were applied: (1) automated cycling with humidified air at 200 °C and 50 mbar water vapor partial pressure, and (2) manual spraying with liquid water followed by desorption at 290 °C in a steam-rich atmosphere. Over 100 cycles, NaX exhibited a gradual decline in water uptake of approximately 25 % under the more severe manual conditions, whereas NaY maintained nearly constant sorption capacity. These results highlight the markedly higher hydrothermal stability of NaY and underline its potential as a robust adsorbent for advanced thermal energy storage systems.

EXPERIMENTAL SETUP

EXPERIMENTAL PROCEDURE AND TEST CONDITIONS

RESULTS AND DISCUSSIONS

TEMPERATURE LIFT, WATER UPTAKE, AND HEAT RELEASE

HYDROTHERMAL STABILITY

CONCLUSIONS

REFERENCES

CONFERENCE TOPIC

This abstract refers to the conference topics Excess Heat and Resource Recovery from Low-grade Sources and Building the Future: Smart Energy Infrastructure for the Energy Transition.

POWER-TO-METHANE: HEAT INTEGRATION AND TECHNO-ECONOMIC ANALYSIS

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SUMMARY

With increasing energy demand and a growing awareness of the effects of global warming of fossil fuels, integrating renewable energies (REs) into the energy mix has become essential. However, the main disadvantage of REs is the need for energy storage systems to compensate for their intermittency. Power-to-methane storage system (PtM) is one of the possible solutions to reduce CO2 emissions and compensate for renewable fluctuations. This work models and analyzes a 15 MW Power-to-Methane plant that converts surplus renewable electricity into methane via Proton Exchange Membrane (PEM) electrolysis and Sabatier process. Since PtM's main problem is its low overall conversion efficiency, python-based heat exchanger network optimization tool (HEN) is developed to improve energy recovery. A techno-economic analysis (TEA) is also carried out, and the first results show that optimizing HEN synthesis and waste heat recovery are essential to increase overall efficiency and reduce total system cost.

INTRODUCTION

Given the growing concerns over anthropogenic greenhouse gas (GHG) emissions, the energy transition and decarbonization are gaining significant attention across the academic and industrial sectors to mitigate climate-change risks. The European Union, an ambitious contributor to the global clean-energy transition, has launched the European Green Deal, which targets at least a 42.5\% share of renewable energy in energy consumption and at least a 55\% reduction in GHG emissions by 2030, and legally binds the objective of achieving carbon neutrality by 2050 [1]. In the coming years, REs will likely account for a high share of the energy mix. However, a well-known issue with RE sources is grid management due to their inherent fluctuations, creating an imbalance between production and energy demand. Energy storage systems (ESS) are therefore essential: they enable time-shifting of electricity consumption and improve the match between supply and demand, resulting in significant cost savings.

Power-to-gas (PtG) shows great potential as an ESS for improving grid control, thanks to its large long-term storage capacity. These systems convert surplus renewable energy into gaseous energy vectors such as hydrogen, methane, methanol, or other chemical carriers. One of the most common pathways in PtG systems is Power-to-Methane, which converts renewable electricity into hydrogen and then into methane via the Sabatier reaction. Compared to hydrogen, methane is an appropriate chemical carrier: it is safer and easier to store and can be transported through the existing gas infrastructure, allowing flexibility between electricity and gas networks. Although PtM has a high storage capacity and a long discharge period, the main disadvantage is lower efficiency than other ESS options. Therefore, the present study focuses on energy optimization using advanced heat-integration technique, targeting an optimal heat-exchanger-network (HEN) design to improve system efficiency and reduce total costs through optimal waste-heat recovery. The main components of the proposed plant are modeled to simulate the proposed PtM system, and thermoeconomic analyses are conducted to assess total costs and discuss further improvements to the system.

POWER TO METHANE CASE STUDY

This study considers a 15 MW PtM plant based on the Sabatier process, producing methane by reacting hydrogen and carbon dioxide at high temperature and pressure. The process comprises three main subsystems: hydrogen production by an electrolysis unit, CO2 capture by absorption, and a methanation unit based on a catalytic reaction (see Fig. 1**)**. Proton Exchange Membrane electrolysis used to convert 15 MW of renewable electricity by splitting water into hydrogen and oxygen via an electrochemical reaction. CO2 is captured in an absorption unit, where flue gas is scrubbed in an absorption column using the chemical solvent monoethanolamine (MEA). The rich solvent is pumped to a stripper and heated to release a high-purity CO2 stream for the methanation unit. Hydrogen and CO2 are then thermochemically converted into methane and water in a series of tubular catalytic reactors. Waste heat generated within the system is recovered through heat integration and used to cover the process heating demand, improving the overall efficiency of the plant. To thermo-economically analyze the PtM system, Python and DWSIM software are used to model and perform steady-state simulations. Each developed unit is validated against data from the literature. Python/Pyomo is then used to develop an optimization tool for designing the PtM heat-exchanger network via a mixed-integer nonlinear programming (MINLP) superstructure approach.

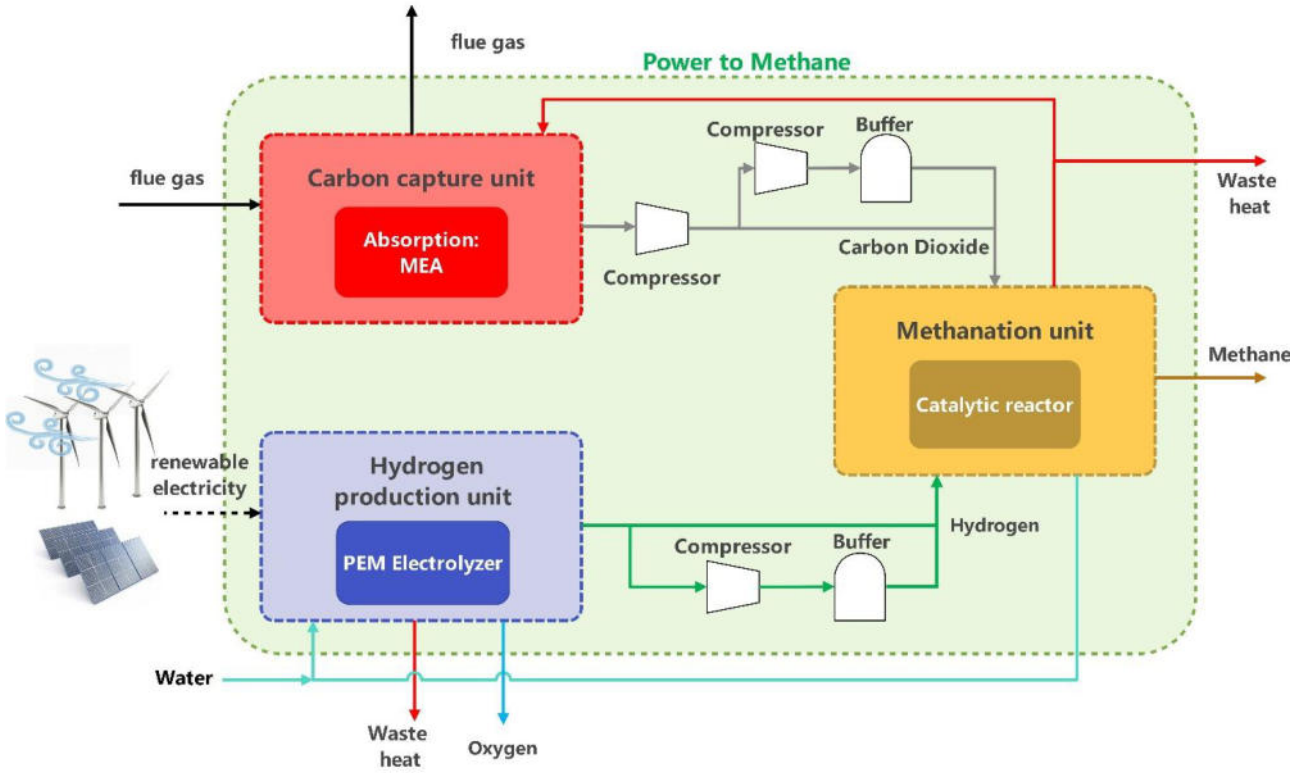


FIG. 1. POWER TO METHANE LAYOUT

REFERENCES

[1] European Commission, (n.d.), Renewable energy targets. Directorate-General for Energy, Brussels, Belgium. Available at: https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-targets_en.

[2] Toro, C. and Sciubba, E., 2018. Sabatier based power-to-gas system: Heat exchange network design and thermoeconomic analysis. Applied Energy, 229, pp.1181-1190.

[3] Salomone, F., Marocco, P., Ferrario, D., Lanzini, A., Fino, D., Bensaid, S. and Santarelli, M., 2023. Process simulation and energy analysis of synthetic natural gas production from water electrolysis and CO2 capture in a waste incinerator. Applied Energy, 343, p.121200.

[4] Hidalgo, D. and Martín-Marroquín, J.M., 2020. Power-to-methane, coupling CO2 capture with fuel production: An overview. Renewable and Sustainable Energy Reviews, 132, p.110057.

[5] Chauvy, R., Verdonck, D., Dubois, L., Thomas, D. and De Weireld, G., 2021. Techno-economic feasibility and sustainability of an integrated carbon capture and conversion process to synthetic natural gas. Journal of CO2 Utilization, 47, p.101488.

CONFERENCE TOPIC

Hydrogen and Green Gas in Integrated Energy Systems

DYNAMIC PLANNING AND OPERATION OF DISTRICT HEATING SYSTEMS WITH FLEXIBLE GEOTHERMAL SOLUTIONS

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SUMMARY

Decarbonizing urban heating is one of the major challenges in the European energy transition. District heating (DH) networks provide a key opportunity to integrate renewable and waste heat sources at scale, but their operation must become more flexible in order to respond to temporal fluctuations in energy demand and renewable supply. This paper develops and applies a dynamic techno-economic modelling framework that integrates both investment planning and supply dispatch optimization for DH systems.

The framework captures variations in demand, fuel prices, and renewable availability on an hourly and seasonal basis, while also considering technology lifetimes, investment costs, and operational constraints. Within this context, we focus on flexible geothermal-based solutions:

- Reversible Organic Rankine Cycle (revORC) systems, which can switch between heat pump and power generation modes, enabling sector coupling and enhancing operational adaptability.

- Borehole Thermal Energy Storage (BTES), which provides both diurnal and seasonal storage capacity, balancing demand and renewable fluctuations.

By applying the framework to representative DH scenarios, we assess how different technology portfolios perform under decarbonization pathways.

KEYWORDS:

District heating; Dynamic modelling; Supply dispatch; Investment optimization; Flexible geothermal solutions; Reversible Organic Rankine Cycle (revORC); Borehole Thermal Energy Storage (BTES); Energy flexibility; Decarbonization; Techno-economic assessment

INTRODUCTION

Heating and cooling account for nearly half of Europe's final energy consumption, making the sector central to achieving climate neutrality. DH networks are particularly suited to integrate renewable and waste heat sources while offering opportunities for system-wide efficiency gains. However, the increasing penetration of variable renewable energy sources (RES) requires DH systems to move beyond static operation and adopt flexible, adaptive strategies that can accommodate temporal mismatches between supply and demand.

Geothermal energy is a promising candidate for providing both baseload and flexible heat supply. Yet, its role in dynamic DH system operation remains underexplored, especially when coupled with advanced technologies such as revORC systems and Underground Thermal Energy Storage (UTES). revORC units can switch between power

generation and heat pump operation, thereby enabling sector coupling and increasing system responsiveness. Similarly, BTES offers the ability to balance seasonal demand fluctuations and improve renewable utilization.

To investigate these opportunities, this paper develops a techno-economic optimization model for dynamic planning and operation of DH systems. The model integrates investment and dispatch decisions, explicitly considers temporal variations, and evaluates how flexible geothermal solutions can enhance both system efficiency and cost-effectiveness. By applying the framework to representative case studies, the paper aims to provide insights into the design of resilient and sustainable DH supply portfolios that can adapt to evolving energy market conditions.

ABSTRACT

This paper presents a dynamic modelling framework for DH systems that couples investment planning with operational dispatch optimization. The framework minimizes total system costs while accounting for temporal variability in heat demand, fuel prices, and renewable energy availability, as well as technical and economic constraints such as technology lifetimes and storage capacities. A particular emphasis is placed on flexible geothermal-based solutions, namely revORC systems and BTES. revORC technologies provide dual functionality by switching between power generation and heat pumping, while BTES enables seasonal storage and enhanced integration of fluctuating renewable energy sources. Representative case studies are used to examine the techno-economic performance of different DH technology portfolios under decarbonization pathways. Results demonstrate that integrating revORC and BTES increases operational flexibility, can reduce system costs, and enhance renewable utilization. The findings highlight the importance of combining dispatch optimization with long-term investment planning and underscore the critical role of flexible geothermal solutions in supporting resilient, cost-effective, and low-carbon DH systems.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: **1.08. Future District Heating and Cooling Solutions**

SYSTEM EVALUATION OF OPTIMIZED DISTRICT HEATING NETWORKS

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SUMMARY

District heating (DH) systems supply 6,6 % (2023) of the total end energy demand in Austria via a total pipe length of 6,100 km (2023). Heat is supplied to households (share of 47%), public buildings (share of 37%) and industry (share of 16%). Primary energy sources used for DH systems are 54% renewable (combustion of biomass and biogenic residues from industries). Many biomass-based DH networks and systems constructed during the past 20 to 30 years are meanwhile facing a need for retrofitting and modernization, including technical measures to increase efficiency of renewable generation, digitalization concepts for optimized network control, as well as business models for DH operators, customers and technology providers. Two national research projects, BM-Retrofit and Fossilfree4Industry, develop, showcase and evaluate retrofitting and optimization concepts. This contribution presents selected results of a system evaluation of demonstrators in these projects based on the methods of life cycle assessment and multiregional input-output macroeconomic modelling.

INTRODUCTION

Currently about 2,400 biomass heating plants and about 150 biomass CHP plants with typically up to 10 MW thermal capacity supply to DH networks in Austria. While biomass-based DH plays a major role as an efficient and flexible solution for the energy transition, boundary conditions for biomass-based DH operators have changed considerably, concerning the need for retrofitting and modernization of the existing systems, integration of other renewable energy sources and the increasing number of buildings with low heating demands. Biomass-based DH systems in general have the potential for intelligent integration and combination of other renewable energy sources, waste heat, storage, heat consumers and the coupling with industry and infrastructure. In order to increase overall efficiency, cost-effectiveness as well as GHG emission reduction, systemic retrofitting and expansion concepts are required, including technological control strategies, storage integration, integration of further renewable energies and waste heat from industry, flexibilization, attractive business models and stakeholder cooperation models. The two national funded research projects BM-Retrofit and Fossilfree4Industry develop DH model solutions and concepts which are demonstrated and validated in selected demonstrator sites.

METHOD

In both projects, the technical, economic and ecological benefits and impacts of the realized retrofitting and modernization measures within the demonstrators are investigated. The evaluation is based on the methods of life cycle assessment (LCA) and macroeconomic modelling. The main objective of the LCA is to compare the global warming potential (GWP) and the primary energy demand of the demonstrator DH systems to reference

cases without the implementation of the developed measures. The macroeconomic analysis of the value chains is based on GLOB-IO, an environmental extended multiregional input-output macroeconomic model to analyse direct, indirect and induced economic impacts, such as the effects on regional value-added and employment.

CASE STUDIES

Results of two case studies are presented. One represents a typical small-scale biomass DH system in Austria with about 2 MW heat load, characterized by a significant share of heat from an fossil oil boiler and an inefficient biomass boiler operation, especially during summer when the heat load is low. In the project BM-Retrofit, the system is extended by a heat pump using waste heat from a hydropower cooling cycle, but also by storage integration, optimization of combustion and model-predictive control using yield and load forecasts. The second case study in the project Fossilfree4Industry aims to establish an inter-municipal heat network along the Weiz-Gleisdorf axis as association of currently five individual DH systems, including concepts for tripling DH supply to ensure a sustainable energy supply for the industrial companies located along the axis, by integrating all locally available renewable sources (geothermal energy, solar thermal energy, waste heat, etc.).

Results of LCA and of macroeconomic modeling are presented for these two case studies. Since results are currently being finalized, they will be included in the full conference paper.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:

2.04 Life Cycle Assessment
1.07. Flexibility and Stability in Thermal and Electric Grids
1.08. Future District Heating and Cooling Solutions
1.15. Sustainable Renovation and Energy Retrofits

ROBUST FEATURE RELEVANCE AND BUILDING CLUSTERING FOR HEAT DEMAND AND RETURN TEMPERATURE FORECASTING IN DISTRICT HEATED MULTI DWELLING RESIDENTIAL BUILDINGS

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SUMMARY

Accurate and robust forecasts of building-side heat demand and return temperature (RT) are essential for 4th/5th generation district heating (4/5GDH), which depends on renewable integration, low supply and return temperatures, storage scheduling, peak shaving, and decentralised production. RT is of particular importance for operators, as it directly determines production efficiency and overall network performance.
As a first step toward robust forecasting, historical consumption data at the building level, focusing on multi-dwelling residential buildings (MDBs), must be analysed to identify parameters that are both meaningful and transferable across different buildings. The goal of this study is to establish a minimal feature set for clusters of MDB, jointly targeting heat demand and RT. We systematically compare (i) temporal resolutions, (ii) lag structures and inertia-aware aggregates (e.g. degree-hours, moving means, diurnal amplitude), and (iii) operational versus meteorological drivers.

Keywords: district heating, heat demand forecasting, return temperature, feature selection, robustness, multi dwelling residential buildings

INTRODUCTION

MDB connected to district heating exhibit diverse demand patterns shaped by building physics, occupant behaviour, and internal system configuration. For flexible low-temperature operation, operators require forecasts that are both accurate and robust across seasons, buildings, and regimes. Return temperature plays a decisive role: high RT reduces network efficiency and hinders integration of low-temperature supply, whereas reliable RT forecasts enable efficient production planning, particularly in smaller or decentralised grids. This work focuses on identifying robust, interpretable predictors while compressing high-frequency signals into compact features that reduce noise and data burden. Features must be (i) practically feasible, available from standard metering, and (ii) of genuine forecasting value. The central question is therefore: Which features are truly relevant for forecasting, and which add little benefit compared to their acquisition and processing effort?

RESEARCH QUESTIONS & HYPOTHESES

RQ1: Can raw outdoor-temperature time series be replaced by compressed descriptors (daily mean, diurnal amplitude) without material accuracy loss for day-ahead forecasts of demand and RT?
RQ2: Which operational variables (flow, supply/return, ΔT) remain indispensable once weather inputs are compressed?
RQ3: Do minimal feature sets transfer across clusters defined by internal system type and demand dynamics?

METHODOLOGY

Our methodological workflow consists of four main stages: (i) data acquisition and preprocessing, (ii) pre-analysis and building clustering, (iii) feature engineering, and (iv) model-agnostic evaluation of feature relevance.

(i) Data acquisition and preprocessing.
We analyse residential substation data together with meteorological records from three European regions (Berlin/Germany, Malmö/Sweden, Bozen/Italy). The forecasting targets are (a) building heat demand and (b) primary-side return temperature (RT). Outdoor temperature is included both as raw time series and as compressed descriptors (daily mean μT_{daily}, diurnal amplitude AT_{daily}, and degree-hours). Analogous compressions are tested for RT. Temporal descriptors (hour-of-day, weekday, season) and explicit lag structures capture inertia effects. Since solar radiation is rarely measured at the building level, we test single-station radiation against temperature-based proxies (diurnal amplitude, degree-hours, astronomical daylength).

(ii) Pre-analysis and clustering.
To stabilise feature relevance across diverse buildings, we group them into clusters with similar demand dynamics. Preprocessing includes normalisation (demand scaled to floor area, optionally detrended against outdoor temperature) and profile extraction (daily heat load and RT profiles at 15-min or hourly resolution, separated by heating, shoulder, and summer/DHW regimes). Clustering is performed using correlation and dynamic time warping (DTW) distances, applied to daily shapes and intensities (daily energy integrals). Both k- means and hierarchical clustering are tested, with Silhouette and Davies–Bouldin indices used to assess cluster quality. Clusters are then annotated with system metadata (e.g., space heating only, DHW storage, instantaneous DHW) and performance indicators (RT overshoot, ΔT stability).

(iii) Feature engineering.
Candidate predictors are grouped into four categories:

- Temporal descriptors (hour-of-day, weekday, season),
- Lagged histories of demand, RT, and weather,
- Meteorological drivers (temperature, wind, radiation and proxies),
- Operational signals (flow, supply, return, ΔT, regime indicators).

(iv) Model-agnostic evaluation.
We evaluate feature relevance using representative statistical and machine learning forecasters, employed solely as validation tools. Robustness is quantified via blocked time-series cross-validation and rolling-origin tests. To identify minimal feature sets, minimal feature sets are identified through ablation studies, where small accuracy losses are considered non-material. Stability is assessed by the frequency of feature selection across folds and buildings, as well as the transferability of minimal feature sets between clusters.

REFERENCES

Geysen, D., De Somer, O., Johansson, C., Brage, J., & Vanhoudt, D. (2018). Operational thermal load forecasting in district heating networks using machine learning and expert advice. Energy and Buildings, 162, 144–153. https://doi.org/10.1016/j.enbuild.2017.12.042
Schäfer, M., Calikus, E., Nowaczyk, S., Sant'Anna, A., & Gadd, H. (2020). Exploring smart heat meter data: A co-clustering driven approach to analyse the energy use of single-family houses. Energy and Buildings, 208, 109629. https://doi.org/10.1016/j.enbuild.2019.109629
Weber, S. A., Fischlschweiger, M., Volta, D., & Geisler, J. (2025). Feature selection for specific prediction targets at the user level in a district heating network. Scientific Reports, 15(29789). https://doi.org/10.1038/s41598-025-15777-0

CONFERENCE TOPIC

This abstract refers to the following conference topic: 1.05 Digitalization for Smart, Resilient Energy Systems, 1.08. Future District Heating and Cooling Solutions

ADVENT OF THE 'METAL AGE' OF THERMOELECTRICITY: GREEN POWER GENERATION AND COOLING BY METALLIC THERMOELECTRICS

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SUMMARY

Thermoelectric (TE) materials directly transform heat into electricity and vice versa, making them promising for applications in power generation or cooling. However, state-of-the-art semiconductors in the focus of current research so far have not made the leap into broad applications due to poor mechanical properties and low power density. Metallic materials would be superior in this regard, but remained largely neglected over the past decades due to their small Seebeck coefficient *S*.
Based on recent advances in realizing ultrahigh TE performance in metals, here we suggest a paradigm shift towards metallic TE, as they offer pivotal advantages over semiconducting materials. This way, a variety of new applications at the heart of today's digital society come into reach – powered by 'green energy' from TE devices exploiting otherwise unused heat reservoirs.

INTRODUCTION

Thermoelectric (TE) materials directly transform thermal into electrical energy and vice versa, making them promising for applications in power generation or cooling. However, state-of-the-art semiconductors in the focus of current research so far have not made the leap into broad applications due to poor mechanical properties and low power density. Metallic materials would be superior in this regard, but remained largely neglected over the past decades due to their small Seebeck coefficient S.

Here we realize ultrahigh TE performance in metals via tuning of electronic interband scattering – an innovative enhancement principle cardinally different from those applied in semiconductors so far. In particular, we boost S by selectively reducing the mobility of holes as they scatter off localized states, leveraged by electronic bandwidth tuning. Using this paradigm, we recently discovered record-high power factors (PF) of 34 $mWm^{-1}K^{-2}$ in binary Ni_xAu_{1-x} alloys, yielding the highest $zT \approx 0.5$ among all metals [1]. Despite this unprecedented TE performance, the high cost of Ni_xAu_{1-x} poses difficulties for applications. We have therefore continued our quest for metallic TE with superior functional properties from more abundant elements. Utilizing an automated materials screening approach, we discover ultrahigh PF up to 11 $mWm^{-1}K^{-2}$ near room temperature in the textbook metal Ni_3Ge [2]. In our search for novel physical mechanisms to tailor electronic scattering, we identify topological flat bands induced by geometrical frustration as a powerful tool to boost the performance of metallic TE beyond the record-high performance of Ni_xAu_{1-x} [3]. With the novel family of kagome metals $zT > 1$ at room temperature is within reach – even exceeding state-of-the-art semiconductor thermoelectrics [3].

This recent progress in fundamental research opens up a variety of new applications utilizing metallic TE. On the one hand, decentralized power generation from local heat sources, in particular otherwise unused waste heat, may be utilized to power up wireless devices by 'green energy'. Especially in view of the Internet of Things (IoT) it would be extremely beneficial to have electricity generated right at the position of the consumer without the need for long cables, batteries or any moving parts at all. On the other hand, metallic TE are ideally suited for active

cooling – an emerging field with rapidly growing applications in microelectronics, optoelectronics, high-power RF devices and bioanalytical platforms. For this purpose , an active and fast heat transfer from a hot spot to a bath at ambient temperature is realized by the ultrahigh power factors of metals that add up to their innately high thermal conductivity. I will review the most striking 'game-changer' applications that finally come into reach with the advent of the *Metal Age of Thermoelectricity*.

KEY WORDS

Thermoelectric Generator (TEG), Low-Grade Waste Heat Recovery, Flexible Energy Harvesting, Industrial Decarbonization, Scalable Clean Technology

REFERENCES

[1] Garmroudi, F.; Parzer, M.; Riss, A.; Bourgès, C.; Khmelevskyi, S.; Mori, T.; Bauer, E.; Pustogow, A., *Sci. Adv.* **9**, eadj1611 (2023). https://doi.org/10.1126/sciadv.adj1611
[2] Garmroudi, F.; Di Cataldo, S.; Parzer, M.; Coulter, J.; Iwasaki, Y.; Grasser, M.; Stockinger, S.; Pázmán, S.; Witzmann, S.; Riss, A.; Michor, H.; Podloucky, R.; Khmelevskyi, S.; Georges, A.; Held, K.; Mori, T.; Bauer, E.; Pustogow, A., *Sci. Adv.* **11**, eadv7113 (2025). https://doi.org/10.1126/sciadv.adv7113
[3] Garmroudi, F.; Serhiienko, I.; Parzer, M.; Riss, A.; Grasser, M.; Stockinger, S.; Khmelevskyi, S.; Pryga, K.; Wiendlocha, B.; Held, K.; Mori, T.; Bauer, E.; Pustogow, A., *Phys. Rev. X* **15**, 021054 (2025). https://doi.org/10.1103/PhysRevX.15.021054

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers: 1.06. Excess Heat and Resource Recovery from Low-grade Sources

DH STATUS ASSESSMENT AS CONTRIBUTOR TO ASSET MANAGEMENT

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SUMMARY

District heating (DH) networks represent a cornerstone of sustainable urban energy systems. However, despite more than five decades of operation, asset management of pre-insulated pipe systems still relies largely on statistical models rather than condition-based assessment. This limitation is primarily due to the lack of reliable analytical methods applicable to the polyurethane (PUR) insulation, which constitutes the most degradation-prone component of DH pipes. This contribution presents results from three analytical techniques—thermogravimetric analysis (TGA), Fourier-transform infrared (FT-IR) spectroscopy, and Laser-Induced Breakdown Spectroscopy (LIBS)—for evaluating the ageing state of PUR insulation in DH networks.

INTRODUCTION

District heating represents a sustainable energy solution by integrating heat generation plants, often utilizing renewable sources or industrial waste heat, and distributing it efficiently to multiple households. This system significantly reduces reliance on individual fossil fuel boilers, thereby lowering CO_2 emissions and improving urban air quality. The integration of solar thermal, biomass, and geothermal technologies further enhances its role in facilitating the transition toward climate-neutral and future-oriented residential heating. A critical infrastructure component of district heating systems is the pipeline network, which transports hot water or steam from central plants to end users while minimizing thermal losses. To achieve high efficiency and long service life under elevated temperature and pressure conditions, these pipelines require advanced insulation systems and corrosion-resistant materials. Although district heating networks have been in operation for more than five decades, asset management by municipal energy suppliers still primarily relies on statistical models. This dependence arises from the lack of reliable, non-destructive methods for assessing the condition of pre-insulated pipes and related infrastructure. Pre-insulated pipes consist of a steel inner pipe, surrounded by polyurethane (PUR) foam for thermal insulation, and an outer protective casing. Over time, these structures are subjected to mechanical and thermal stresses, such as those induced by thermal expansion, as well as chemical degradation of the PUR insulation.

The present study addresses this gap by investigating the applicability of three analytical techniques for assessing the degradation state of polyurethane, which represents the most vulnerable component of district heating pipes. Thermogravimetric analysis (TGA), a method commonly employed to evaluate the thermal stability of organic materials, was first demonstrated by Ozawa et al. to enable the determination of activation energies associated with thermal degradation reactions. Subsequent advances by Chang allowed activation energies to be obtained from single measurements, and later work by Puentes-Parodi revealed that these values correlate with the ageing time of PUR in district heating pipes. Based on this foundation, TGA was applied to samples from various municipal suppliers to evaluate degradation levels. Results indicate that many pipes retain acceptable residual

activation energies even after several decades of service, implying a remaining service life before mechanical failure, as confirmed through comparison with laboratory-aged samples.

Complementary techniques were also employed. Fourier-transform infrared (FT-IR) spectroscopy, as shown by Vega et al., provides spectral indicators of PUR degradation. By correlating spectra from laboratory-aged samples with those of field-aged pipes, FT-IR analysis was confirmed as a suitable tool for assessing insulation ageing. Additionally, Laser-Induced Breakdown Spectroscopy (LIBS) was applied to support and validate findings obtained by TGA and FT-IR.

Comparison of these results with standardized measurements according to EN 253 demonstrated strong agreement, confirming that multiple parameters consistently reflect the gradual loss of material properties over time. Among the methods, TGA in particular shows promise as a reliable indicator of residual service life. Importantly, the approach requires only minimal amounts of PUR material, making it feasible for integration into routine asset management practices. This includes opportunistic sampling during the establishment of new connections, or the installation of fittings and branch lines, thereby providing a practical pathway toward condition-based management of district heating infrastructure.

REFERENCES

Green, C., (2018), Heating Systems for Houses, A Design Handbook. James & James (Sience Publishers) Ltd., London, UK.

CONFERENCE TOPIC

Please indicate here to which of the Conference Topics this abstract refers:
1.08. Future District Heating and Cooling Solutions
1.15. Sustainable Renovation and Energy Retrofits
Support Schemes for Implementation in Buildings, Industry, Districts, Cities and Regions
2.04. Life Cycle Assessment
2.08. Spatial Energy Planning with Emphasis on Renewable Energies

CO-OPTIMIZING INTEGRATED ENERGY SYSTEMS FOR ENHANCING THERMAL-TO-ELECTRIC FLEXIBILITY: MODELING OF HEAT FLOW DIRECTIONS

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SUMMARY

The growing integration of intermittent renewable energy sources (RESs) increases the need for operational flexibility in power systems. Conventional district heating (DH) networks, constrained by fixed unidirectional flow, offer limited adaptability. This paper presents a novel co-optimization framework that couples electricity and new-generation district heating (NGDH) networks to enhance system-wide flexibility. Mass flow direction is treated as a decision variable, enabling bidirectional operation. By incorporating nonlinear hydraulic and thermal constraints—including pressure drops, temperature-dependent heat losses, and flow-temperature interactions—the proposed formulation captures the physical reality of heat transport more accurately than simplified models. To preserve tractability, the original mixed-integer, nonlinear, and non-convex problem is reformulated using second-order cone programming, McCormick envelopes, and outer approximation methods. Numerical experiments show that bidirectional thermal flow control can reduce total operational costs and improve renewable integration compared to conventional unidirectional strategies.
Keywords: Bidirectional district heating, co-optimization, integrated energy systems, sector coupling, thermal-to-electric flexibility

INTRODUCTION

The EU's 'Fit for 55' package targets a 55% reduction in carbon emissions from 1990 levels [1], supporting Germany's 65% reduction goal by 2030 and achieving carbon neutrality by 2045 [2]. While the electrical sector is transitioning to renewable energy, the heating sector still depends on fossil fuels, accounting for over one-third of global CO2 emissions. 4th generation district heating (DH) systems facilitate decarbonization by integrating thermal and electrical energy through sector coupling, optimizing renewable energy for heating with Combined Heat and Power (CHP) and Heat Pumps (HP) [3]. These systems face modeling complexities requiring nonlinear optimization to manage hydraulic and thermal dynamics. Unlike traditional unidirectional flow models, modern 4th and 5th generation DH systems introduce bidirectional mass and energy flow within the network, enabling multiple heat "prosumers".

Building on the existing literature, this study advances the operation of integrated energy systems (IES) by (i) treating DH mass flow direction as a decision variable; (ii) implementing a control strategy that jointly optimizes supply temperatures and mass flow rates (iii) reformulating the nonlinear and non-convex problem into tractable forms using McCormick envelopes, SOCP, outer approximation and linearization techniques; and (iv) comparing traditional unidirectional and optimized bidirectional configurations to evaluate and benchmark operational flexibility in IESs.

MODELING FRAMEWORK

The model minimizes the total operating cost of the combined electricity and DH system. A simplified lossless DC power flow represents the power grid, capturing generation limits, transmission capacities, and nodal voltage angles while keeping the formulation computationally efficient.

The DH network is described with a thermo-hydraulic model that tracks pressure and temperature at every node. In the hydraulic model, heat water is transferred through DH network, with hydraulic constraints ensuring mass flows and pressure relationships throughout the system. The hydraulic constraints describe the mass flow rate continuity at all nodes. Pressure losses to friction in pipelines are modelled using the Darcy-Weisbach equation [4]. The thermal constraints govern temperature dynamics, heat losses and time delays caused by pipe length and flow velocity within the supply and return pipelines and heat generated at heat sources and delivered through the network to the consumers at heat exchange stations.

Coupling between the two systems occurs through coordinated operation of CHP units and HPs. To account for bidirectional flows, the unidirectional Darcy-Weisbach equation is replaced by allowing the mass flow to be positive, negative, or zero based on pressure difference. Flow direction is decomposed using auxiliary variables that activate only one direction at a time, while upper bounds keep all pipelines within thermal and hydraulic limits. This integrated representation captures key physical and operational constraints of a thermal–electric energy system in a tractable form.

RESULTS AND CONCLUSION

The analysis of this work quantifies the flexibility in terms of reduced operational costs, comparing systems modeled with unidirectional and bidirectional mass flows. It is demonstrated that incorporating mass flow directions as state variables reduces total system costs and increases wind power utilization. However, this numerical analysis is highly case-dependent.

The primary challenge lies in the accurate modeling of the nonlinear and non-convex heat flow dynamics within DH networks, encompassing both thermal and hydraulic equations, resulting in computational challenges and tractability issues. To address it, advanced techniques such as McCormick Envelopes, SOCP, and outer approximation were applied. However, they may overestimate the flexibility of the system. Notably, while the inclusion of bidirectional mass flow in the optimization model was shown to have no significant impact on overall approximation accuracy, it introduces an exponential increase in computational complexity with increasing number of network nodes.

REFERENCES

[1] European Commission, “Fit for 55”: delivering the EU’s 2030 Climate Target on the way to climate neutrality., (2021). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550 (accessed December 26, 2024).
[2] Bundesamt für Justiz, Bundestag D. Bundes-Klimaschutzgesetz (KSG)., (2021). https://www.gesetze-im-internet.de/ksg/BJNR251310019.html (accessed December 26, 2024).
[3] H. Lund, S. Werner, R. Wiltshire, S. Svendsen, J. Eric, F. Hvelplund, B. Vad, 4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems, Energy 68 (2014) 1–11. https://doi.org/10.1016/j.energy.2014.02.089.
[4] G.O. Brown, The History of the Darcy-Weisbach Equation for Pipe Flow Resistance, 40650 (2002). https://doi.org/10.1061/40650(2003)4.

CONFERENCE TOPIC

1. Technologies and Systems for Buildings, Industry, Districts, Cities and Regions

- 1.07. Flexibility and Stability in Thermal and Electric Grids

SUPPORTING DHC OPERATORS IN THE DECARBONISATION OF THEIR SYSTEMS

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Internet: www.wip-munich.de, www.supportdhc.eu

INTRODUCTION

At present district heating and cooling (DHC) contributes around 12% of the final energy consumption for space heating and hot water with about 25% of the heat supply from renewable energy sources (RES)[15] and a large remaining part still from fossil fuels, often coal and natural gas. Higher rates of RES have been so far only achieved in countries such as Sweden, Denmark, Austria, Estonia, Lithuania, Latvia and Iceland. However, in almost all current long-term studies, the transformation of the DHC sector is identified as one of the central keys to the urban heat transition and thus to the overall goal of a carbon-neutral Europe by 2050[16]. To fulfil this role, extensive technical DHC measures are necessary, ranging from the conversion of heat generation to renewable and climate-neutral energy sources to the expansion, densification, and modernization of DHC. For the desired transformation of the DHC sector, necessary investments totalling to about 600 B.€ are estimated[17].

THE CHALLENGE

In the next three decades, the implementation of required measures will be particularly challenging for owners and operators of DHC systems and all related stakeholders, such as authorities, involved in this process. The main challenges are (1) the necessary investments in the DHC infrastructure and related implementation efforts itself are enormous (2) Article 26 of the Energy Efficiency Directive (EED) with a decarbonisation roadmap of the sector until 2050 must be fulfilled, and (3) technologies such as low-grade renewable energies (RE) and waste heat (WH) are new to many operators and create the need of technical support to many subprocesses of DHC transformation and investment planning. Thus, the overall objective of the SUPPORT DHC project is to address these challenges by supporting a fast implementation of low-grade renewable energy and waste heat for DHC in Europe.

THE SUPPORT DHC PROJECT

The overall objective of the SUPPORT DHC project (co-funded by the LIFE Programme of the European Union; contract no. 101119914; 2023-2026) is to support a fast implementation of low-grade renewable energy (RE) and waste heat (WH) for district heating and cooling (DHC) in Europe. This is achieved by supporting DHC operators in drawing-up transformation plans leading to efficient DHC systems as defined in the Energy Efficiency Directive revision and in particular concrete investment plans for a fast implementation of packages of low-grade RE and WH measures. In six European countries (AT, DE, IT, LT, PL, UA), the SUPPORT DHC project in cooperation with involved DHC operators demonstrates such processes and leads to investments on the ground for a variety of EU-wide DHC system cases.

[15] European Commission: „District Heating and Cooling in the European Union: Overview of Markets and Regulatory Frameworks under the Revised Renewable Energy Directive“, 2021, https://energy.ec.europa.eu/district-heating-and-cooling-european-union_en
[16] https://climate.ec.europa.eu/eu-action/european-green-deal/european-climate-law_en
[17] District heating investment to reach Heat Roadmap Europe 2050 Scenario, IEA, 2020

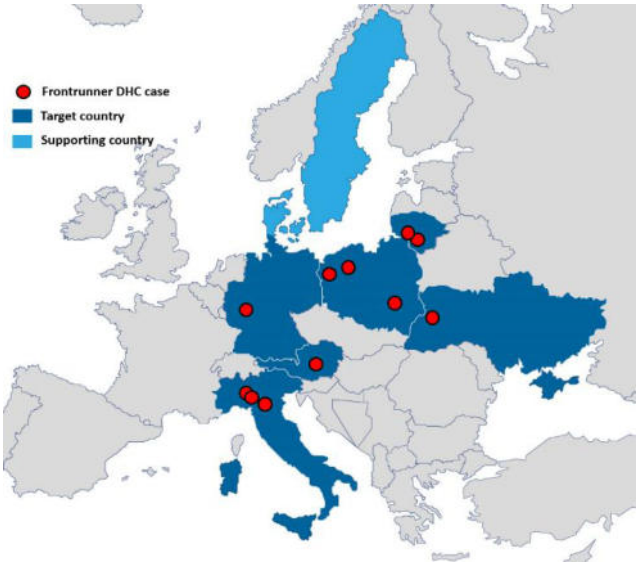


Fig. 1: Geographical focus of SUPPORT DHC

The support of DHC operators is rolled-out through a 3-step approach, as shown below:

1. Extensive support is provided to 11 DHC frontrunner cases,
2. minimum 27 follower cases are selected during the project and supported, and
3. more than 100 DHC operators are reached by replicating support services also in countries beyond the SUPPORT DHC target countries.

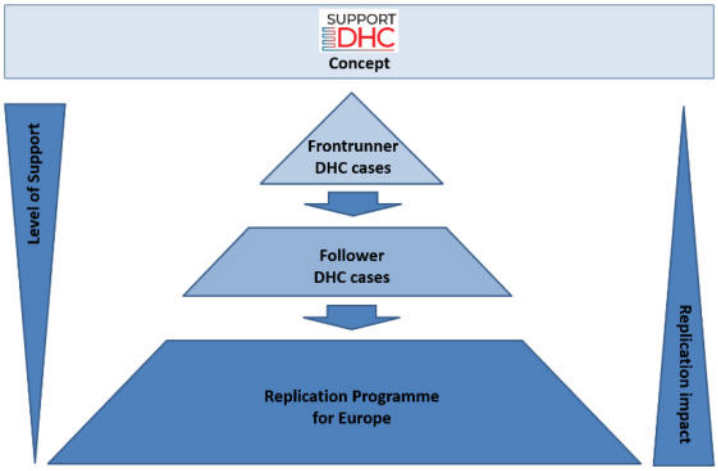


Fig. 2: 3-step approach of SUPPORT DHC

The project further aims at capacity building of DHC operators for managing and steering such processes and of the specific service providers and other stakeholders for supporting transformation and investment planning. At policy and regulatory level, local and regional authorities will become enablers of transformation measures as the project addresses solutions for removing barriers and framework shortcomings. Furthermore, also at national and EU levels, market and framework barriers and solutions will be identified and fed into the political decision-making processes. Know-how gained in the SUPPORT DHC project will be disseminated to further EU DHC markets and replication will be actively organised.

CONFERENCE TOPIC

1.08. Future District Heating and Cooling Solutions

Co-funded by the European Union

ADVANCED HEAT LOAD CALCULATION METHODS FOR ENERGY-EFFICIENT RESIDENTIAL BUILDINGS

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SUMMARY

In practice, the heat load is used to design heating system components and also to determine the necessary heat output of heat supply systems in buildings. There are three different standardized calculation methods that take different factors into account and are to be applied depending on the design case. In the case of room-by-room building heat load calculation for the design of heating system components, ÖNORM H 7500-1 (1), as cited in the law, applies in Austria. The HL-(N)ZEB project is investigating these three standardized methods and comparing them with results from dynamic building simulation, a non-standardized method developed and used in practice (2), the Passive House Planning Package (PHPP) (3), and monitoring data from existing buildings. The aim is to identify significant deviations to subsequently formulate proposals for adapting those standards.

INTRODUCTION

There are already showcase projects in which, for example, only 50% of the calculated heat load according to ÖNORM H 7500 was installed and the required heat output could still be covered. (4) This has enabled a significant reduction in investment and operating costs for heating and cooling. These projects are the reason for further investigations, to standardize the reduction in the calculated heat load.
Particularly in the case of optimized building envelopes and technology in future-proof nearly zero-energy buildings (NZEB) with continuously improving average U-values, the calculated heat load deviates significantly from the actual heat output required. At present, there is no standardized calculation method for the room-by-room heat load of buildings with an average U-value < 0.5 [W/m²K].

METHOD

The standards ÖNORM H 5056 (energy performance certificate), ÖNORM H 7500-1 (1) and ÖNORM H 7500-3 (5) are taken into account for the relevant research principles. Part 1 of ÖNORM H 5056 (6) specifies the calculation of the heating energy demand - based on the usage profiles of the hot water and heating energy demand - and Part 2 enables the validation of the corresponding results from software programs.
Appropriate methods for calculating the heat load of buildings by their heat losses under standardized conditions are defined in ÖNORM H 7500-1 (1) for buildings with an average U-value ≥ 0.5 W/(m²K). In addition, a simplified procedure for these calculations is formulated in ÖNORM H 7500-3 (5). The calculations in this standard are formulated using the envelope area method for existing buildings that are heated under design conditions.
In addition to the standard calculations, the method according to PHPP (3) is also used to compare the very different approaches.

Furthermore, building models of 22 test buildings are created in IDA ICE (7) and the heat load is determined using dynamic building simulations.
The results of all these calculation methods are then compared with monitoring data for the respective buildings. In this way, the differences between the calculation methods and the deviation from the actual heat load required can be analysed.

FIRST RESULTS

This graph compares the ÖNORM H 7500-3 (5) standardized heat load calculation result (in Fig. 1 first bar on the left) with heat load data/results, using the methods described in Table 1, for one of the existing buildings regarded. In order to smooth out short-term fluctuations in the simulation results and monitoring data, for example due to user behavior or control effects, moving averages are calculated over a 6 hour period.

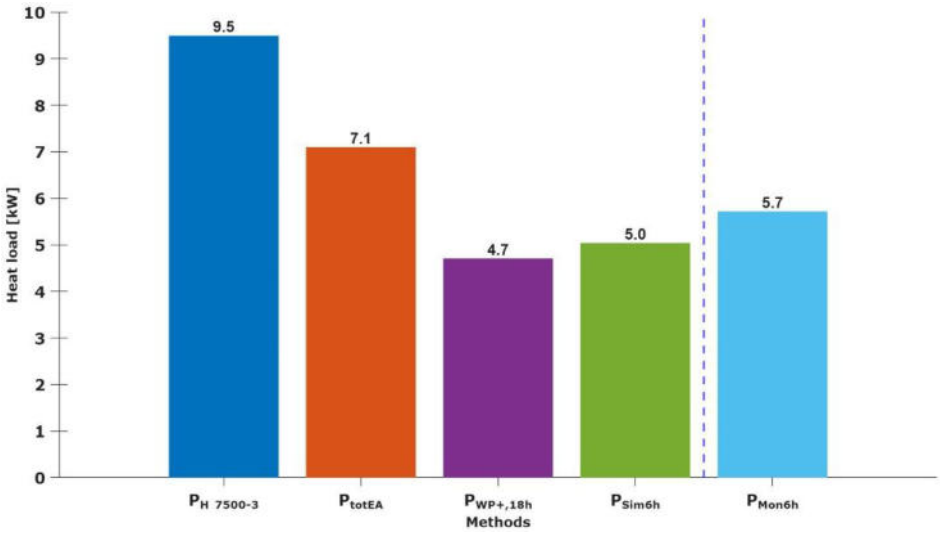


Fig. 1: Heat load data/results comparison for test building 21

Table 1: Heat load data/results definitions

$P_{H\ 7500\text{-}3}$	Calculation according to ÖNORM H 7500 -3 (5)
P_{totEA}	Heat load estimate according to energy performance certificate (ÖNORM H 5056-1) (6)
$P_{WP+,18h}$	Heat load calculated using an alternative calculation method in an Excel spreadsheet for 18 hours of full load operation of the heat pump per day (2)
P_{Sim6h}	Highest heat load from 6-hour averages in the simulated period with real climate data (7)
P_{Mon6h}	Highest heat load based on 6-hour averages of the monitoring data

NEXT STEPS

After sending out a short survey to all 22 building owners, more detailed building information to further improve the simulation models, will be available. Conduct heat load calculations using various approaches and methods for all reference buildings. Analysis, evaluation, and comparison of the measured residential buildings with regard to heat load deviation, followed by evaluation of the main influencing factors. As a result, proposals for adjustments to the heat load calculation for new buildings (U-value < 0.5 [W/m²K]) are being submitted to the Austrian Standards Committee. The first results of the study show a potential, that adjusting the standardized calculation methods can prevent an oversizing of building heating systems in future construction projects.

REFERENCES

1. **Austrian Standards International.** ÖNORM H 7500-1:2015. *Heizungssysteme in Gebäuden - Verfahren zur Berechnung der Norm-Heizlast für Gebäude mit einem mittleren U -Wert >= 0,5 W/(m2 · K) - Nationale Ergänzung zu ÖNORM EN 12831.* Wien : Austrian Standards International, 2015.
2. **Komposch, A. D.** *Vereinfachte Heizlast-Tool.* [Computer Software] s.l. : RGK e.U., 2024.
3. **Feist, Dr. Wolfgang, et al.** *Passivhaus Projektierungs Paket Version 7 (2012).* [Computer Software] Darmstadt : Passivhaus Institut, 2012.
4. **Grim-Schlink, Margot, Preisler , Anita und Stipsits, Alina.** *Heizlast optimieren - Strategien zur Vermeidung von Überdimensionierung bei Wärmepumpen.* [Magistratsabteilung 20 – Energieplanung] Wien : e7 Energie Markt Analyse GmbH, 2020.
5. **Austrian Standards International.** ÖNORM H 7500-3:2014. *Heizungssysteme in Gebäuden - Teil 3: Vereinfachtes Verfahren zur Berechnung der Norm-Gebäudeheizlast.* Wien : Austrian Standards International, 2014.
6. —. ÖNORM H 5056-1:2024. *Gesamtenergieeffizienz von Gebäuden – Teil 1: Ermittlung des Heiztechnikenergiebedarfs.* Wien : Austrian Standards International, 2024.
7. **EQUA Simulation AB.** *IDA Indoor Climate and Energy, Version 5.1.1.* [simulation- and planningtool] Solna, Stockholm : EQUA Simulation AB, 2025.
8. **Hottinger, M.** *Klima und Gradtage in ihren Beziehungen zur Heiz- und Lüftungstechnik.* Zürich, Schweiz : Springer Berlin, Heidelberg, 1938. 978-3-642-89885-3.

CONFERENCE TOPIC

Policy Frameworks and Support Mechanisms for Renewable Heating and Cooling

THERMAL ACTIVE SURFACES AS DRIVERS OF PASSIVE COOLING STRATEGIES. A STUDY OF PUBLIC OFFICE BUILDINGS IN MEXICO CITY.

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SUMMARY

Rising temperatures in Mexico City have driven higher air conditioning use and CO_2 emissions. This research proposes an Emergy Framework to support a Building Stock Model and Retrofit Models, focusing on low-tech strategies that improve thermal comfort in public office buildings while minimizing active cooling. A GIS-based web tool documents baseline consumption, embodied carbon, and retrofit scenarios for urban-scale decision-making. The study applies a hybrid Top-Down and Bottom-Up method to define four archetype buildings from a sample of 65 offices, based on climate zone, typology, footprint, and construction system. Retrofit models are assessed using LCA and LCC, prioritizing energy efficiency, embodied carbon, and architectural context.
Preliminary results show that energy performance does not directly correlate with building age. Compared with ASHRAE and Mexican standards, performance ranked: Contemporary (1982), Historic (1797), Contemporary (1983), and Post-Revolution (1946). The research highlights the feasibility of strategies like photovoltaic integration and passive measures (thermal mass, insulation, natural ventilation) as viable pathways for sustainable retrofitting and resilience in Mexico City.

INTRODUCTION

Over the past three decades, the imperative to reduce CO_2 emissions and implement energy transitions has significantly influenced both architectural discourse and practice. In pursuit of greater energy efficiency, the focus has often been on material optimization and mechanical systems—particularly in office buildings with high occupancy and ventilation demands. However, low-tech strategies—when carefully designed and contextually adapted—can also deliver high levels of performance, offering a resilient and climate-responsive alternative.
This research reframe energy not as a constraint but as a generative design condition. It proposes that architecture, through its material and spatial strategies, can fulfil energy goals without defaulting to technological overdependence.

PROJECT DESCRIPTION

Due to rising temperatures and global warming, Mexico City has seen a surge in air conditioning use, leading to increased CO_2 emissions. This research proposes an Emergy Framework to support a Building Stock Model and Retrofit Models, specifically aimed at improving thermal comfort in public office buildings with minimal reliance on air conditioning. The study will record baseline energy consumption, embodied CO_2, and energy required for supply processes, all documented in a GIS-based web tool to support urban-level decision-making.

The research follows three main steps:

Building Stock Model: This phase categorizes buildings based on specific attributes to identify Archetype Buildings that represent the broader building stock.
Retrofit Models: Low-tech retrofit strategies are developed and assessed based on economic, environmental criteria. Indicators include Life Cycle Assessment (LCA) and Life Cycle Cost (LCC). These models aim to harmonize Energy Efficiency, Embodied Carbon, and architectural context, addressing critical gaps in existing retrofit models.
Web Tool Platform: This tool enables consistent documentation, environmental impact evaluation, and energy reduction strategy design, facilitating solutions for urban-scale retrofitting.

The research highlights the need for a holistic approach and aligns with Mexico's climatic context, reducing dependence on fossil fuels. The study will focus on 65 office buildings in Mexico City as an initial Building Stock sample, which allowed us to select 4 archetypes to be analyzed in detail. The Archetype`s selection was based on climate zone, typology, footprint size, and construction system, and incorporates low-tech strategies such as photovoltaic integration, deemed feasible in the region.

Research Question: Is it possible to achieve energy-efficient operation of existing office buildings without active cooling and ventilation systems, while maintaining occupant comfort, by optimizing passive measures (thermal mass, insulation, and natural ventilation)?

Method: A Hybrid Method combining Top-Down and Bottom-Up analysis is applied to define Archetype Buildings that represent the Building Stock, informed by critical variables like climate region, building characteristics, and energy concepts.

Preliminary Results: Analysis of four archetypes reveals that spatial configuration and envelope performance are more critical to energy outcomes than construction era. Low-tech strategies, such as external shading, thermal mass utilization, and night ventilation, and radiant hydronic systems show strong potential—particularly when integrated with design intelligence rather than mechanical compensation.
This framework provides a comprehensive model for energy-efficient retrofitting in Mexico City's public office buildings, prioritizing sustainability and resilience.

The web tool platform is initially developed, and regarding the timing and resources frame it will be developed as a prototype.

REFERENCES

Nägeli, C., et all. (2020), Towards agent-based building stock modeling: Bottom-up modeling of long-term stock dynamics affecting the energy and climate impact of building stocks, Energy and Buildings. (Science Direct) Volume 211, 2020, 109763, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2020.109763.
Loga, T., & Stein, B. (2015). Deutsche Wohngebäudetypologie. Beispielhafte Maßnahmen zur Verbesserung der Energieeffizienz von typischen Wohngebäuden. DOI: 10.13140/RG.2.2.11714.50881

CONFERENCE TOPIC

1.5 Sustainable renovation and Energy Retrofits

A DESIGN METHODOLOGY FOR SOLAR DISTRICT HEATING SYSTEMS USING PYTHON AND TRNSYS

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SUMMARY

The sizing of solar district heating (SDH) systems with pit thermal energy storage (PTES) and heat pumps (HP) is conventionally performed using detailed tools (e.g TRNSYS, Modelica etc). While accurate, these simulations are computationally intensive and unsuitable for large parametric studies due to large simulation time. Traditional thumb rules, such as fixed collector-to-storage ratios expressed in m^2/m^3, are often used as a shortcut but become unreliable when the load profile or integration constraints deviate from standard assumptions. For example, when PTES discharge is limited by the pipe diameter at the integration point, the achievable solar fraction and storage utilization can differ substantially from conventional design guidelines. Such conditions necessitate case-by-case evaluation, for which a fast sensitivity tool can provide valuable guidance. We propose a two-stage methodology. In the first stage, a Python-based model is developed which integrates solar collectors, pit thermal energy storage, and a heat pump, resolving hourly boundary conditions with sub-hourly thermo-hydraulic dynamics. The tool performs random sampling across a million combinations of component's sizes which enables rapid evaluation of energy balances and techno-economic indicators. In the second stage, only the most promising configuration(s) are re-simulated in TRNSYS, where collector physics, diffuser layouts, hydraulics, and soil–storage coupling are fully represented. This workflow provides a computationally efficient yet physically consistent approach for robust SDH system sizing, offering a faster alternative to direct TRNSYS optimization while maintaining reliability.

METHODOLOGY

A Python-based simulation model is developed which integrates solar collectors, a stratified PTES, and a HP. It resolves hourly solar yield, demand, and boundary temperatures while simulating sub-hourly thermo-hydraulic dynamics within the storage. Stratification is represented through vertical discretization of the PTES, with explicit treatment of advection, axial conduction, and surface heat transfer. Losses are simulated using a transient one-dimensional soil domain that captures heat transfer into the surrounding ground, providing a more realistic representation of long-term losses. The Python tool was benchmarked against TRNSYS across a wide range of operating conditions and system configurations.

The proposed design workflow consists of two main stages, and is implemented for the Härnösand district heating network in Sweden, using demand, boundary, and cost data supplied by the local utility. In the first stage, a The Python tool employs stochastic sampling across the design space with each configuration evaluated on an multi-year energy balance. An integrated economic module calculates the levelized cost of heat (LCOH), and parallel execution on multi-core processors enables evaluation of over one million configurations within practical runtimes, thereby facilitating systematic screening of feasible system sizes. In the second stage, a TRNSYS model is employed to refine and validate the pre-feasibility results. This model involves higher details than in python model, accounting for hydraulic piping and diffuser layouts within the PTES, and captures soil–storage heat transfer through transient ground conduction models. . Using these detailed simulations, a final techno-economic assessment based on component capital and operating costs is performed to determine the final optimized system design.

CASE STUDY AND SYSTEM

The district heating system in Härnösand has an annual heating demand of 208 GWh. The heat supply is provided through a mix of six different sources. As shown in Figure 1, the majority of the heat is recovered from the combined heat and power (CHP) plant's turbine condenser and flue-gas condenser, with the CHP plant fueled primarily by wood chips, contributing 128 GWh annually. Industrial waste heat (30 GWh) represents a low-cost and efficient energy source within the system and is therefore not targeted for replacement by solar thermal integration. Accordingly, this study focuses on the remaining heat demand, excluding the portion already met by industrial waste heat. The system configuration analysed is shown in Figure 2

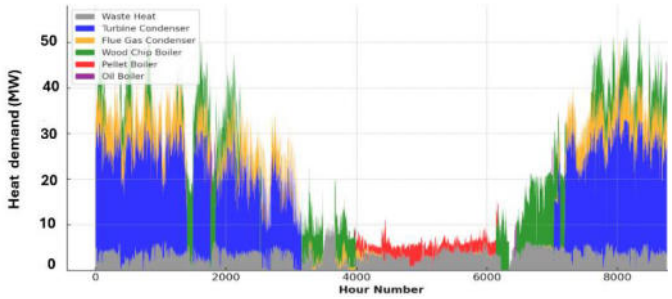


Figure 1 Distribution of the heating demand met by various heat sources at the district heating plant in Härnösand, Sweden.

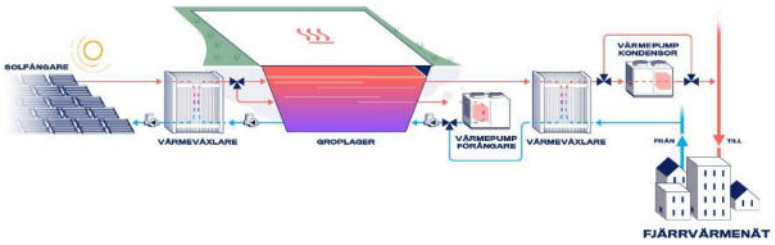


Figure 2 A simplified illustration of the simulated system configuration. From the left the figure shows the solar thermal collectors, the heat exchanger to charge the PTES, the PTES and heat exchanger for heating the return water from the network.

RESULTS

The Python model was validated against TRNSYS for a wide range of system configurations, including variations in collector field size, PTES volume, and HP capacity. Across all cases, the Python tool reproduced annual heat delivery within 10–15% of the TRNSYS results, with a consistent tendency to slightly underpredict delivered heat. Storage heat losses were overestimated by about 3–5%, reflecting the simplified charging and diffuser representation. Electricity consumption of the HP was typically 4–6% higher, linked to the absence of mid-level charging diffusers that improve COP in the TRNSYS model. Despite these differences, seasonal dynamics and performance trends were captured reliably, demonstrating that the Python tool provides conservative but sufficiently accurate estimates for pre-feasibility screening. Random sampling over more than one million configurations yielded significant insights into the techno-economic dynamics of system design, highlighting the value of the tool for guiding detailed simulations.

CONFERENCE TOPIC

1.13 Renewable heating and cooling for low, medium, and high temperature applications.

LIFE CYCLE ASSESSMENT OF THERMOSYPHON AND PV HOT WATER SYSTEMS IN A SIDE-BY-SIDE SETUP IN NAMIBIA

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SUMMARY

The rising global demand for hot water underscores the transition towards solar-based technologies. In alignment with emission reduction targets, Namibia seeks to replace conventional electric boilers with solar thermal and PV2Heat systems, prioritizing both cost efficiency and sustainability. This study provides eco-performance data for solar hot water systems, with a focus on thermosiphon and PV configurations installed at the NUST Science and Technology Park. A life cycle assessment (LCA), complemented by monitoring data, forms the basis for evaluating environmental performance. A central aspect is the determination of the levelized cost of electricity (LCOE) to enable robust economic comparison. Drawing on existing studies, the work critically addresses the limitations of forecasting eco-performance indicators while aiming at a direct LCA-based comparison between solar thermal and photovoltaic systems, thereby contributing to Namibia's long-term energy transition strategy.

Keywords: Solar hot water, thermosiphon systems, PV2Heat, life cycle assessment (LCA), eco-performance, levelized cost of electricity (LCOE), Namibia, sustainable energy transition

INTRODUCTION

The worldwide demand for hot water is steadily increasing, reinforcing the urgency of sustainable energy strategies to curb fossil fuel dependence and mitigate environmental impacts. Solar-based technologies are central to these strategies, particularly in the Sunbelt region (20°–40° latitude north and south), which includes Namibia (Weiss & Spörk-Dür 2023). Among the most promising options are solar thermal thermosiphon systems and photovoltaic-powered electric hot water systems (PV2Heat), both projected to dominate the regional solar hot water market by 2030.

Namibia has committed to ambitious climate targets through its Intended Nationally Determined Contributions (NDCs), with a reduction potential of up to 91% by 2030 (Republic of Namibia 2021). In the energy sector, the replacement of conventional electric boilers with thermosiphon and PV2Heat systems constitutes a central pathway, with particular emphasis on cost efficiency to ensure sustainable adoption by end users.

The present study supports this strategy by providing eco-performance indicators and life cycle-based comparisons of these technologies under real environmental conditions. Given the current lack of robust data and comprehensive studies for household-scale applications in Namibia, this work aims to fill a critical research gap and to inform both policy and practice in sustainable hot water supply.

EXPERIMENTAL & MODELING

In the comparative study mentioned in the introduction, which serves as the basis for the life cycle assessment, 3 different hot water systems are examined.

They each consist of a 200-liter tank and collectors/PV modules with 1.2-1.6 kW equivalent rated thermal output/kW peak:

- System 1: Indirect thermosyphon system with a flat-plate collector;
- System 2: Indirect thermosyphon system with evacuated heat pipe collector and
- System 3: PV-to-heat (PV2Heat) system.

The overall aim of the systems under investigation is to carry out a direct comparison of small systems for solar hot water generation, including energy monitoring and determination of the heat generation costs. The three systems are installed in a 12 m long shipping container, with the monitoring system, the controls and the storage tank of the PV2Heat system housed in the container. Figure 1 illustrates the structure of the container. The container is installed in the NUST Science and Technology Park.

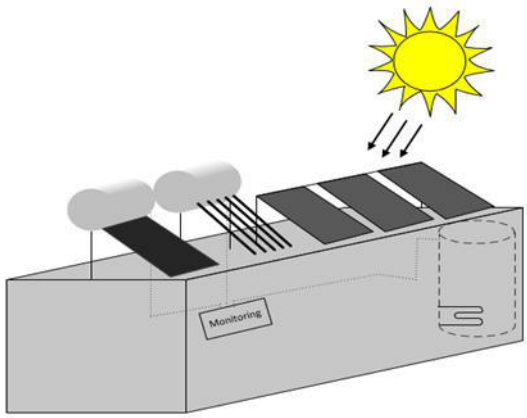


Fig. 1: Experimental setup of the side-by-side comparison of thermosyphon and PV hot water systems

The life cycle assessment (LCA) parameters were determined on the basis of detailed planning and direct on-site data collection at the existing installation. Performance data for the thermosiphon and PV hot water systems were obtained from the completed monitoring phase, thereby providing a robust dataset under real environmental and operating conditions in Namibia. These empirical data formed the central input for the LCA, ensuring that the results reflect actual system performance rather than modeled assumptions.

To strengthen the evaluation and to enable a broader contextualization, comparative results from previous studies (Buckley et al. 2019; Shimhanda et al. 2018; Kicker et al. 2017; Kicker et al. 2018a, 2019; Kicker et al. 2018b) were integrated. This approach allows the eco-performance indicators derived in the present study to be benchmarked against earlier findings, highlighting both improvements and persisting challenges.

The present follow-up study thus provides a comprehensive LCA and eco-performance assessment of solar thermal and PV-based hot water systems in a side-by-side setup. In doing so, it not only generates site-specific evidence for Namibia but also contributes to the international discourse on sustainable hot water supply in Sunbelt countries.

RESULTS AND DISCUSSION

For the preparation of the life cycle assessment (LCA), the generation of the required input data did not present major hurdles. The performance data used for deriving the eco-performance indicators were obtained directly from the monitoring of metrological parameters and the technical specifications of the installed systems. Based on the cost structure of the system components, the levelized cost of electricity (LCOE) was calculated, serving as an economic indicator and forming part of the combined economic and ecological performance assessment.

At the time of writing, the systems remain in the monitoring phase. However, by the completion of this paper, the full monitoring dataset covering all three hot water systems will be available, ensuring a comprehensive empirical basis for the LCA. In addition, data from previous studies (Buckley et al. 2019; Shimhanda et al. 2018; Kicker et al. 2017; Kicker et al. 2018a, 2019; Kicker et al. 2018b) were considered to contextualize the results

and to support the evaluation of trends. Unlike earlier work, the present study provides an absolute and consistent basis for comparison across both solar thermal and PV-based systems under identical operating conditions.
A central outcome of this research is the establishment of a reliable set of eco-performance indicators and LCOE values for thermosiphon and PV2Heat systems in Namibia. The direct side-by-side comparison highlights their respective strengths and limitations and thereby contributes to a more nuanced understanding of sustainable hot water supply in Sunbelt regions.

REFERENCES

Buckley, Angelo Ian; Kritzinger, Karin; Moschik, Rudi; Mamphweli, Sampson; Spörk-Dür, Monika (2019): Comparison of Photovoltaic- and Solar Thermal Hot Water Systems in the South African Context. In Dave Renné, Daniel Mugnier, Jose-Miguel Cardemil, Ken Guthrie, Ricardo Rüther (Eds.): Proceedings of the ISES Solar World Congress 2019. ISES Solar World Congress 2019/IEA SHC International Conference on Solar Heating and Cooling for Buildings and Industry 2019. Santiago, Chile, 04.11.2019 - 07.11.2019. Freiburg, Germany: International Solar Energy Society, pp. 1–12, checked on 11/15/2023.

Kicker H.; Lang R.; Wallner G. (2017): Sustainability Assessment of Solar Thermal Collector Systems. In Dr. Manuel Romero, Dr. Daniel Mugnier, Dr. David Renné, Mr. Ken Guthrie, Dr. Steven Griffiths (Ed.): Proceedings of the ISES Solar World Conference 2017 and the IEA SHC Solar Heating and Cooling Conference for Buildings and Industry 2017: International Solar Energy Society, pp. 2276–2283.

Kicker H.; Wallner G.; Lang R. (2018a): Sustainability Assessment of Most Relevant Solar Thermal Heat Systems. In Dr. Andreas Häberle (Ed.): Proceedings 12th EuroSun Conference on Solar Energy for Buildings and Industry.

Kicker H.; Wallner G.; Lang R. (2019): Life cycle assessment of an allpolymeric ultralowcost nonpumped solar thermal collector system for hot water preparation. In Institute of Thermal Technology, Silesian University of Technology (Ed.): Proceedings of 32nd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems. With assistance of Wojciech Stanek, Paweł Gładysz, Sebastian Werle, Wojciech Adamczyk. Polland.

Kicker H.; Wallner G.; Lang R.; Ramschak T. (2018b): Life Cycle Assessment of a Novel All-Polymeric Pumped Solar Thermal Collector System for Hot Water Preparation. In Universidade do Minho. Departamento de Engenharia Mecânica Campus Azurém, Guimarães Portugal (Ed.): ECOS 2018 - Proceedings of the 31st International Conference on Efficiency, Cost, Optimisation, Simulation and Environmental Impact of Energy Systems. Portugal.

Republic of Namibia (2021): Namibia's NDC UPDATE. UNFCCC. Available online at https://unfccc.int, checked on 11/15/2023.

Shimhanda, S.; Ileka, H.; Shidhika, F. (Eds.) (2018): A comparative Study of Solar Water Heater and Photovoltaic Water Heater in Windhoek: ISEC.

Weiss, W.; Spörk-Dür, M. (2023): SOLAR HEAT WORLD WIDE. Edition 2023. IEA Solar Heating & Cooling Programme, checked on 11/15/2023.

CONFERENCE TOPIC

1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications

OPTIMIZING HYDRAULIC INTEGRATION FOR LARGE-SCALE THERMAL ENERGY STORAGE THROUGH HEAT PUMP CYCLE SELECTION

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SUMMARY

To increase renewable energy use in district heating (DH), large-scale thermal energy storage is essential. Underground Thermal Energy Storage (UTES) enables supply-demand balancing and renewable integration but often operates at temperatures too low for direct network supply. Heat pumps are therefore required to bridge this gap and can expand usable storage capacity by cooling the return flow below the grid's return temperature. This paper evaluates hydraulic integration concepts combined with different heat pump cycles using seasonal performance factor (SPF) and exergy analysis in dynamic Dymola/Modelica simulations. Results show that both heat pump cycle selection and integration strategy strongly influence overall system performance.

Keywords: Exergy Analysis; District Heating; Dynamic Simulations

INTRODUCTION

To enhance the integration of renewable energy in DH systems, UTES is essential, as shown in research projects, like the gigaTES[1] and ScaleUp[2]. However, the supply temperature from UTES is typically insufficient for direct grid use. Heat pumps (HP) provide a promising solution, as they not only bridge the supply temperature gap but also reduce the return temperature of the DH grid, thereby increasing the effective storage capacity. Since heat pump installations require high capital investment, efficient operation—quantified by the Seasonal Performance Factor (SPF), as well as high full load hours -are crucial for economic viability. This study evaluates strategies to maximize SPF and full-load hours by comparing different heat pump cycles and hydraulic integration schemes within dynamic simulations. The results highlight that both the selected cycle and the integration concept substantially influence overall system performance.

METHODOLOGY

Hydraulic adaptations were implemented to accommodate different HP cycles—ranging from single- to multi-stage Perkins–Evans and reverse Brayton to double-stage Osnabrück cycles (see Fig. 14)—based on the two most commonly applied schemes ([3], [4]) shown in Fig. 1, which illustrate the UTES discharging phase. The systems were modeled in Dymola/Modelica, incorporating detailed models of the HP and the UTES and used for dynamic simulations. Their performance was analyzed based on the exergy efficiency and their SPF. This methodology is based to consider a more realistic behavior, like [5] & [6].

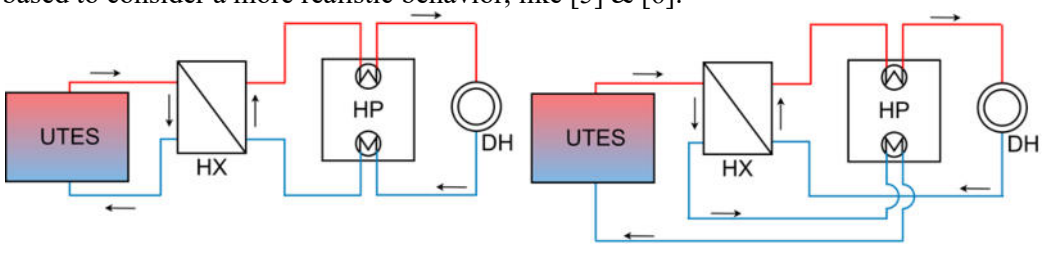


Fig. 13: Baseline system integration schemes of the discharging phase. Left: heat pump sink between DH grid's (DH) return

line and the heat exchanger (HX); Right: heat pump sink between the HX and the cold side of the UTES.

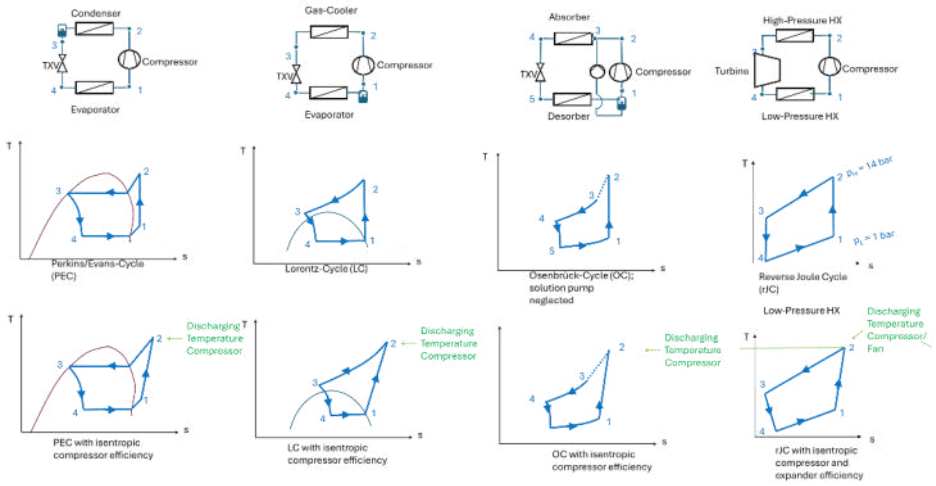


Fig. 14: Overview of different heat pump cycles [7]

RESULTS

Both the HP cycle and integration strategy significantly affect system performance. Considering the DH temperature glide and maximizing return cooling are crucial to increase UTES capacity. Cycles offering a glide during heat absorption—such as reverse Brayton and double-stage Osnabrück—are particularly suited for this application, see Table 1. Variable-speed pumps improve hydraulic efficiency by adapting flow to operating conditions. Using the proposed method, the SPF can be increased by more than 25%, with values of up to 5.

Table 1. Comparison of heat pump cycles for UTES–DH integration

Heat Pump Cycle	Temperature Glide Capability	Complexity	Typical SPF Range	Suitability for UTES + DH
Perkins-Evans (single-stage)	low	low	3.0 – 3.8	moderate
Reverse Brayton	high	medium	3.5 – 4.5	good
Osnabrück (double-stage)	high	high	4.0 – 5.0	very good

CONCLUSION

The study demonstrates that both the choice of HP cycle and the integration strategy strongly affect DH system performance when coupled with UTES. Accounting for temperature glide, reducing return flow, and optimizing mass flow with speed-controlled pumps significantly enhance efficiency and storage capacity. The proposed method is computationally efficient, enabling rapid evaluation and optimization of heat pump concepts in renewable-based DH applications.

REFERENCES

[1] Van Helden, W., et al. (2021) Giga-scale thermal energy storage for renewable districts. Publishable Final Report. https://www.gigates.at/index.php/en/publications/reports
[2] Wien Energie. ScaleUp. Available at URL: https://www.wienenergie.at/scaleup/ (Accessed: 05.09.2025)
[3] Sifnaios, Ioannis, Geoffroy Gauthier, Daniel Trier, Jianhua Fan, and Adam R. Jensen. 2023. "Dronninglund Water Pit Thermal Energy Storage Dataset." Solar Energy 251 (February): 68–76. https://doi.org/10.1016/j.solener.2022.12.046.
[4] Winterscheid, Carlo, and Thomas Schmidt. 2019. Gram District Heating Monitoring Data Evaluation for the Years 2016-2017. PlanEnergi Jyllandsgade 1 9520 Skørping Denmark.

[5] Abdulrahman Dahash, et al. Numerical Analysis and Evaluation of Large-Scale Hot Water Tanks and Pits in District Heating Systems. 16th IBPSA int. Conference. 2019. 2-4 Sept. Rome.
[6] José Joaquín Aguilera, Wiebke Meesenburg, Wiebke Brix Markussen, Benjamin Zühlsdorf, Brian Elmegaard (2024): Real-time monitoring and optimization of a large-scale heat pump prone to fouling-towards a digital twin framework, in Applied Energy, 2024/7/1
[7] Zotter, Gerald, Adler; Bernhard and Langauer, Andreas (2024): A novel heat pumping cycle in a rotation heat pump for latent process heat supply using sensible heat sources 16th IIR-Gustav Lorentzen Conference on Natural Refrigerants (GL2024). Proceedings. University of Maryland, College Park, Maryland, USA, August 11-14 2024, DOI: 10.18462/iir.gl2024.1113

CONFERENCE TOPIC

1.08 Future District Heating and Cooling Solutions or 1.13. Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage

MEMBRANE DISTILLATION: A VERSATILE SEPARATION TECHNOLOGY FOR CIRCULAR ECONOMY AND HYDROGEN PRODUCTION

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SUMMARY

Membrane Distillation (MD) is a thermally driven, pressure-free separation process employing hydrophobic membranes that allow selective vapor transport. This paper investigates the technical principles and potential applications of MD, emphasizing its role in resource recovery, clean water production, and hydrogen electrolysis. Due to its capability to operate at low temperatures (<80 °C), MD is compatible with waste heat integration, enabling energy-efficient water treatment and deionized (DI) water production. Application scenarios include concentration of wastewater, ammonia recovery, and coupling with hydrogen production processes.
Keywords: membrane distillation, hydrophobic membranes, wastewater treatment, ammonia recovery, deionized water, hydrogen electrolysis, circular economy

INTRODUCTION

The rising demand for sustainable water treatment and hydrogen production technologies necessitates efficient, low-energy separation processes. Conventional pressure-driven filtration systems require significant energy input and suffer from limitations in separating volatile compounds. Membrane Distillation (MD) has emerged as a promising alternative due to its unique operating principle: transport of vapor across hydrophobic membranes induced by a temperature gradient. This allows selective separation of water and volatile species such as ammonia while rejecting salts, macromolecules, and non-volatile contaminants.
The relevance of MD extends beyond water purification, offering integration opportunities in circular economy frameworks. By recovering resources such as ammonia and producing high-purity water for industrial processes, MD facilitates synergies between waste treatment and renewable energy sectors, particularly in hydrogen production.

METHODS

MD employs a microporous, hydrophobic membrane that prevents liquid penetration while permitting vapor diffusion. The driving force is the vapor pressure gradient generated by a temperature difference across the membrane. Typical configurations include direct contact MD, air gap MD, and vacuum MD, each with specific thermal and operational advantages.
In the context of hydrogen electrolysis, MD can be applied to treat secondary water sources, such as municipal or industrial effluents. Wastewater is pretreated to remove suspended solids and then subjected to MD, where vapor permeates through the membrane and condenses on the permeate side as purified water. Operating temperatures below 80 °C enable coupling with low-grade waste heat, e.g., from electrolyser cooling systems, thereby reducing external energy requirements.
Furthermore, MD is adaptable for selective ammonia recovery. Volatile ammonia permeates the membrane, where it can be collected in acidic solutions, enabling reuse in fertilizer production. Such dual functionality—clean water generation and nutrient recovery—positions MD as a multi-benefit process within industrial symbiosis.

RESULTS

The characteristics of the treated wastewater used as MD feed and the required specifications for the electrolyser permeate are summarized in **Table 1.** The comparison highlights the need for high separation performance, particularly in reducing electrical conductivity and dry residue.

Table 1: Feed water specifications for Membrane Distillation experiments

Parameter	**Unit**	**Feed Value/Range**	**Target Value**
Electrical Conductivity (EC)	µS cm^{-1}	300 – 1200	10
Iron (Fe)	mg L^{-1}	0.28	1
Chloride (Cl)	mg L^{-1}	not measured	2
Dry residue	mg L^{-1}	250 – 800	7

A laboratory-scale MD plant was adapted and test-runs were carried out for DI water production. The setup is shown in **Figure 1**. Initial trials demonstrated stable operation at low temperatures, confirming feasibility for achieving the required permeate specifications.

CONCLUSION

Membrane Distillation is a versatile separation process with promising applications in circular economy and renewable energy systems. Its ability to operate at low temperatures and recover both clean water and valuable resources makes it suitable for coupling with hydrogen electrolysis, wastewater management, and nutrient recycling. Laboratory tests confirm its potential to meet electrolyser input requirements. Future developments should focus on scaling laboratory findings to industrial implementation, optimizing membrane materials, and further integrating MD into industrial symbiosis frameworks. By linking resource providers with energy and material users, MD can contribute significantly to sustainable production chains.

CONFERENCE TOPIC

Circular Economy Strategies for the Energy Transition

AN AUTOMATED METHODOLOGY FOR THERMAL ENERGY STORAGE SELECTION AND INTEGRATION IN INDUSTRIAL HEAT SYMBIOSIS

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SUMMARY

The study presents a novel methodology for automating the selection, sizing, and operation of thermal energy storage (TES) systems in industrial symbiosis networks. The approach integrates temperature–heat profiles from Total Site Integration with stratified TES modeling, thermo-economic analysis, and day-ahead scheduling. Both sensible and latent (PCM) storage options are evaluated under varying supply–demand scenarios, including schedule fluctuations, outages, and new partner integration. Validation with real data from GreenLab Skive shows that the methodology reduces external heating and cooling demand by up to 16% and achieves CO_2 reductions of 17.3%. The framework provides a robust decision-support basis for resilient, low-carbon, and cost-effective industrial heat recovery.
Keywords: industrial symbiosis, thermal energy storage, automation, flexibility, GreenLab Skive, heat recovery

INTRODUCTION

The urgent challenge of climate change compels industries to adopt ambitious energy efficiency measures to reduce emissions and accelerate the transition toward carbon neutrality [1]. Literature indicates that 20–50% of industrial energy input is lost as exhaust gases, cooling water, and excess heat, collectively referred to as waste thermal energy [2]. Industrial symbiosis (IS), where surplus heat from one facility is integrated as a resource for others, provides a promising pathway to increase energy efficiency, enhance resource utilization, minimize fossil fuel consumption, and mitigate emissions.

However, the discontinuous and fluctuating nature of industrial excess heat streams has long hindered their effective recovery and utilization. In this context, thermal energy storage (TES) plays a pivotal role by decoupling supply from demand while accounting for the interactions between heat sources, storage systems, and utilization processes. Reviews of TES applications for industrial waste heat recovery confirm the availability of multiple storage options [3], yet few studies systematically explore the advantages of different materials and configurations or assess how storage technology selection impacts technical and economic viability [4]. Most existing research addresses storage type, sizing, or operation separately, leaving a gap in integrated approaches that combine technology selection, system dimensioning, cost assessment, and resilience analysis, particularly in the context of industrial heat symbiosis. This study addresses this gap by proposing a holistic methodological framework for TES integration in industrial clusters.

METHODODLOGY

This study proposes a comprehensive methodological framework that integrates temperature–heat profiles of industrial clusters (via total site integration) with stratified TES modeling, thermo-economic analysis, and operational constraints. The framework systematically matches temperature–heat profiles of both sources and sinks, determines optimal storage technologies, defines tank sizing, and stream assignments for efficient heat recovery while ensuring security of supply. It considers both sensible and latent heat storage technologies with

high Technology Readiness Levels (TRLs) [5], recognizing their distinct advantages: phase change materials (PCMs) provide high energy density and precise temperature matching for processes with constant temperature demands (e.g., steam generation), whereas sensible heat storage provides robustness, operational simplicity, and adaptability to processes with variable temperature requirements, such as water preheating or heat pump integration. To further enhance flexibility, the framework incorporates day-ahead scheduling that leverages dynamic energy pricing, enabling storage systems to charge during periods of low electricity prices and discharge during peak demand.

Validation has been carried out using real-world data from GreenLab Skive, an eco-industrial park in Denmark that serves as a large-scale testbed for renewable energy, circular resource use, and industrial symbiosis. The cluster hosts diverse industries, including a straw pyrolysis plant producing biochar and bio-oil, a marine protein facility converting starfish into animal feed, a plastic pyrolysis plant for waste-to-fuel conversion, a biogas plant utilizing agricultural residues, and a 6 MW hydrogen electrolyzer linked to local wind power. These companies provide highly variable heat supply and demand patterns, making GreenLab an ideal case for testing dynamic TES integration. Comparative analyses were performed across multiple scenarios: a baseline without storage, the current centralized concept under varying supply–demand conditions, including schedule variations, temperature fluctuations, and alternative configurations considering new partner integration, plant shutdowns. Key performance indicators—including energy savings (GWh), CAPEX, CO_2 reductions, and supply security—were used to rank TES options in terms of resilience, footprint, and economic viability.

RESUTS AND CONCLUSIONS

Preliminary results at GreenLab confirm that the proposed methodology dynamically adapts TES solutions to changing conditions and temperature- heat profiles of onsite companies located at industrial cluster. For example, under variable operation of major heat suppliers, the model selected a hybrid configuration combining a pressurized hot water tank with four stratified temperature zones (80–130 °C) and latent PCM storage at 130 °C, enabling additional recovery. Compared to the no-storage case, this configuration reduced external heating and cooling demand by up to 16%, and further improved flexibility and reliability. Sensitivity analysis identified critical uncertainties, such as batch process operating hours and TES cost functions, that strongly influence economic metrics like Net Present Value (NPV) and Payback Period (PBP). The methodology thus provides can be used as based for development of decision-support tool that dynamically adapts TES configuration and operation to supply–demand variations, offering a robust foundation for resilient, low-carbon industrial heat symbiosis networks.

REFERENCES

[1] Adom, K., Bekoe, W., Amuakwa-Mensah, F., Mensah, J.T., Botchway, E., (2012), Carbon dioxide emissions, economic growth, industrial structure, and technical efficiency: empirical evidence from Ghana, Senegal, and Morocco on the causal dynamics, Energy, 47, 314–325.

[2] Cabeza, L.F., Fernández, A.I., Barreneche, C., Ushak, S., (2015), PCM storage, Handbook of Clean Energy Systems, 4, 1–23.

[3] Miró, L., Gasia, J., Cabeza, L.F., (2016), Thermal energy storage (TES) for industrial waste heat (IWH) recovery: a review, *Applied Energy*, https://doi.org/10.1016/j.apenergy.2016.06.147

[4] Manente, G., Ding, Y., Sciacovelli, A., (2022), A structured procedure for the selection of thermal energy storage options for utilization and conversion of industrial waste heat, *Journal of Energy Storage*, 51, 104411, https://doi.org/10.1016/j.est.2022.104411.

[5] Brückner, S., Liu, S., Miró, L., Radspieler, M., Cabeza, L.F., Lävemann, E., (2015), Industrial waste heat recovery technologies: An economic analysis of heat transformation technologies, *Applied Energy*, 151, 157–167, https://doi.org/10.1016/j.apenergy.2015.01.147.

CONFERENCE TOPIC

Excess Heat and Resource Recovery from Low-grade Sources

A REGION'S TRACK RECORD IN TRANSFORMING ITS ENERGY SYSTEM

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SUMMARY

The EnergieZukunft WEIZplus (EZWp) cooperative aims to transition an entire region comprising 41 municipalities and over 120,000 residents to a 100% renewable energy supply from local sources, thereby demonstrating a transferable model path to climate neutrality. As part of the ´100% Erneuerbare-Energie-Reallabore´ programme initiated by the Austrian Federal Ministry for Innovation, Mobility and Infrastructure (formerly BMK), a regional innovation laboratory was established that combines research, project development, knowledge transfer and citizen participation. A key focus is on implementing projects that create not only ecological but also social and economic added value. Initial successful projects include the establishment of energy communities, innovative citizen participation facilities (photovoltaics, storage, heating networks) and spatial energy planning in practice. The results so far show that decentralised structures, collaborative action and participatory business models can achieve broad acceptance and accelerate the energy transition.

Keywords: energy transition, energy communities, citizen participation, photovoltaics, storage, regional energy systems, innovation

INTRODUCTION

The energy transition represents not only a technological transformation, but also a societal one. Previous research projects have mostly focused on smaller pilot regions [1]; EnergieZukunft WEIZplus eGen, on the other hand, works at a regional level, encompassing seven climate and energy model regions (KEM), 41 municipalities and different economic structures.

EZWp's vision is clearly formulated: a completely renewable energy supply based on local value creation, participatory organisational models and regional innovation cycles. The aim is to replace fossil fuel heat sources with solar thermal energy, biogenic raw materials and environmental heat, triple the share of electricity and gradually replace fossil fuel mobility with electric mobility and biofuels.

Particular attention is being paid to energy communities as new social and organisational structures. They enable citizens, municipalities and SMEs to generate, use and trade energy together. Supplemented by citizen participation facilities such as photovoltaic parks or storage solutions, the energy transition becomes a tangible experience and is actively supported by the population.

METHODOLOGY AND STRUCTURE

The cooperative organisational structure provides the basis for acceptance, transparency and broad participation [3]. EZWp eGen acts as the sponsor of an innovation laboratory, which serves as a central point of contact for information, consulting, data management, project development and financing.

The methodology is based on three interlocking levels:

1. Regional data and potential analysis

- o Survey of energy demand and renewable potential (PV, wind, biomass, solar thermal, environmental heat).
- o Identification of deficits and surpluses in the energy system.

2. Socio-economic integration

- o Establishment of energy communities (EEG, BEG) as a platform for joint action.
- o Development of citizen participation models that democratise access to projects and keep value creation in the region [2].

3. Innovation ecosystem

- o Linking municipalities, businesses, industry, science and the population.
- o Use of pilot projects (e.g. 'Fossilfree4Industry', inter-municipal heating networks) to develop transferable model solutions.

The governance structure makes it possible to bring together research, business and citizens to establish new financing, business and operating models.

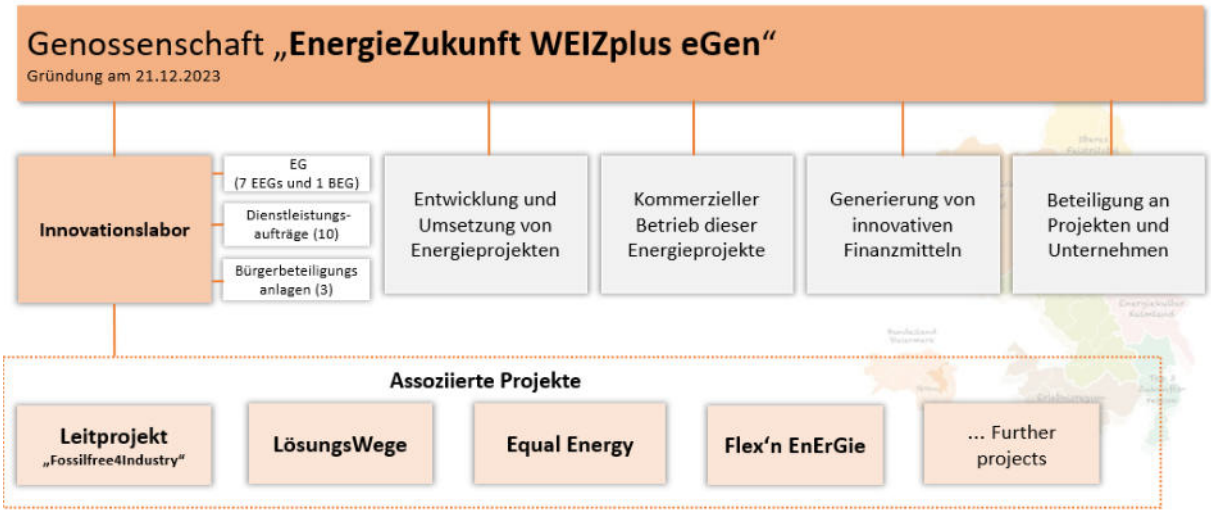


Fig. 1: Organisation structure of the EnergieZukunftWEIZplus cooperative

RESULTS

Since its foundation in December 2023, significant milestones have been achieved:

- **Energy communities**
  Seven EEGs and one BEG with a total of 1,313 active metering points are in operation. By July 2025, 300,000 kWh of renewable energy had already been traded within these structures. Participants range from private households to municipalities and SMEs.
- **Citizen participation plants**
  Initial test projects, such as a 20 kWp PV plant, have been successfully implemented via a citizen participation platform. Larger projects are currently underway, including a 300 kWp agri-PV system and a 250 kWp rooftop system for a municipal building. The latter will increase the local self-sufficiency rate to up to 40%. At the same time, storage systems are being developed to increase flexibility and security of supply.

- **Innovation and research projects**

Fossilfree4Industry is an inter-municipal heating network based on biomass, ORC processes, solar thermal energy and heat pumps. Covering 95 kilometres of routes and with a capacity of 60 MW, private individuals, municipalities and industry are equally involved in order to guarantee security of supply and optimise resource use.
The following research projects are also being worked on: Flex'n EnErGie (energy communities), Equal Energy (energy efficiency), Lösungswege (mobility of the future), as well as climate neutrality roadmaps for the cities of Weiz and Gleisdorf and much more.

- **Knowledge transfer:**
  Results and information are disseminated in a targeted manner using various knowledge formats. This has enabled high-profile events such as 'Transform Energy 2025' to be held with up to 200 participants. Furthermore, specialist events such as ´Energy Talks´ on the topic of smart PV systems were held. The content of EnergieZukunft is made accessible to a broad audience at yearly events such as the 'Fest der Umwelt" in Gleisdorf.

The results so far show that a combination of holistic regional cooperation, regional structures, innovative technologies, citizen participation and governance instruments can create a sustainable energy system. The WEIZplus project thus serves not only as a regional real-world laboratory, but also as a blueprint for the successful design of energy systems.

REFERENCES

(1) Weber, Matthias & Kubeczko, Klaus. (2022). APCC SR Strukturen für ein klimafreundliches Leben: Kapitel 13. Innovationssystem und -politik Kapitel 13. INNOVATIONSSYSTEM UND -POLITIK.

(2) Frankenberg, D., Niebuhr, A., & Peters, J. C. (2025). Strukturschwache ländliche Räume als Gewinner der Energiewende?. Wirtschaftsdienst, 105(6), 423-427

(3) Kelly, R., & Mbah, M. (2024). Regionale Energiewende-Governance zur Co-Transformation zukunftsfähiger Energieinfrastrukturen als Daseinsvorsorge im ländlichen Raum. *Raumforschung und Raumordnung/Spatial Research and Planning*, *82*(2), 127-142.

CONFERENCE TOPIC

2.01 Financing and Business Models (Bürgerbeteiligungen)
2.03 Gerechter und inklusiver Mechanismus für die Energiewende (Soziale EEG´s))
2.07. Intelligente Dienste und Systembetrieb (Energiegemeinschaften, THG Bilanz)

A KINETICS-BASED METHODOLOGY FOR EVALUATING THE LONG-TERM THERMAL STABILITY OF PHASE CHANGE MATERIALS USING DSC

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SUMMARY

Accurate lifetime evaluation of phase change materials (PCMs) is essential for reliable thermal energy storage systems, yet durability assessments based mainly on thermal cycling often fail to capture degradation during extended isothermal operation. This work develops and validates an experimental methodology combining differential scanning calorimetry (DSC) in hermetically sealed medium-pressure crucibles with isoconversional kinetic analysis and independent isothermal tests, applied to two organic PCMs, xylitol and palmitic acid, relevant for low- to medium-temperature thermal energy storage. Dynamic DSC measurements under oxidative conditions enable detection of degradation-related exothermic processes masked in conventional systems due to evaporation, which are directly linked to latent heat loss and used as kinetic observables for lifetime estimation, while complementary inert-atmosphere experiments clarify the role of oxygen.

INTRODUCTION

The transition towards climate-neutral energy systems requires efficient thermal energy storage (TES) technologies to improve energy efficiency and facilitate the integration of intermittent renewable sources. In this context, phase change materials (PCMs) are attractive due to their high energy storage density and near-isothermal operation, particularly for low- to medium-temperature applications such as solar thermal systems and building climatization. Despite their favourable thermophysical properties, the long-term reliability of PCMs remains a critical challenge. During operation, PCMs are subjected not only to repeated melting and solidification cycles but also to prolonged exposure at elevated temperatures, which can lead to gradual degradation manifested as latent heat loss or changes in phase transition behaviour.

Durability assessments are commonly based on thermal cycling tests (Ferrer et al., 2015); however, these primarily probe degradation associated with phase transitions and often overlook processes occurring under extended isothermal conditions, which are highly representative of real operation. Recent studies indicate that even chemically stable organic PCMs may undergo subtle degradation during long-term isothermal exposure (Majó et al., 2021; Wusiman et al., 2025). These limitations highlight the need for experimental methodologies capable of capturing time-dependent degradation mechanisms under realistic thermal conditions.

METHODOLOGY AND CHARACTERIZATION

An experimental methodology combining dynamic and isothermal differential scanning calorimetry (DSC) with isoconversional kinetic analysis was developed to evaluate the long-term thermal stability of phase change

materials (PCMs). Two representative organic PCMs, xylitol and palmitic acid, were selected due to their different chemical structures and relevance for low- to medium-temperature thermal energy storage. Dynamic DSC measurements were performed in hermetically sealed medium-pressure crucibles to suppress evaporation and enable detection of degradation-related thermal events. Experiments were conducted under oxidative and inert atmospheres using multiple heating rates to generate suitable datasets for kinetic analysis.
The degradation process was associated with an exothermic signal appearing after fusion under oxidative conditions, which was selected as the kinetic observable. Kinetic parameters were obtained using Friedman's isoconversional method without assuming a specific reaction mechanism. When degradation resulted in partial loss of latent heat, the degree of conversion was rescaled to ensure consistency between the kinetic observable and the effective loss of storage capacity. Independent isothermal DSC tests were carried out at selected temperatures to validate the kinetic predictions through direct monitoring of fusion enthalpy evolution.

RESULTS AND CONCLUSIONS

Dynamic DSC measurements in sealed crucibles revealed an exothermic process appearing after fusion under oxidative conditions for both xylitol and palmitic acid, whereas no such signal was detected under inert atmosphere. This exothermic event was identified as the main indicator of thermal degradation and was directly linked to the loss of latent heat storage capacity. Xylitol exhibited a well-defined degradation process leading to complete disappearance of the fusion enthalpy, with average activation energies close to 90 $kJ \cdot mol^{-1}$. In contrast, palmitic acid showed a more complex behaviour with lower activation energies, around 64 $kJ \cdot mol^{-1}$, and only partial loss of latent heat, preserving approximately 83% of its initial enthalpy. After rescaling the kinetic conversion to the degradable enthalpy fraction, consistency between the kinetic observable and the functional loss of storage capacity was ensured.
Independent isothermal DSC tests showed good agreement with kinetic predictions, validating the reliability of the methodology for lifetime estimation. Complementary experiments under inert atmosphere confirmed the decisive role of oxygen in activating degradation processes, as no measurable enthalpy losses were observed in its absence. Overall, the proposed methodology provides a predictive framework for assessing PCM thermal lifetime and highlights the limitations of durability evaluations based solely on thermal cycling.

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REFERENCES

Ferrer, G., Solé, A., Barreneche, C., Martorell, I., & Cabeza, L. F. (2015). Review on the methodology used in thermal stability characterization of phase change materials. In Renewable and Sustainable Energy Reviews (Vol. 50, pp. 665–685). Elsevier Ltd. https://doi.org/10.1016/j.rser.2015.04.187
Majó, M., Sánchez, R., Barcelona, P., García, J., Fernández, A. I., & Barreneche, C. (2021). Degradation of fatty acid phase-change materials (PCM): New approach for its characterization. Molecules, 26(4), 1–11. https://doi.org/10.3390/molecules26040982
Wusiman, K., Wang, T., Shi, L., & Dai, X. (2025). Thermal stability study of sugar alcohol phase change materials by multi-indicators under inert gas protection conditions. Solar Energy Materials and Solar Cells, 281. https://doi.org/10.1016/j.solmat.2024.113318

CONFERENCE TOPIC

Renewable Heating and Cooling Solutions for Low, Medium and High Temperature Applications Emerging Heat and Cold Storage.

DIRECT GENERATION OF COMPRESSED AIR FROM LOW-TEMPERATURE WASTE HEAT

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SUMMARY

Low-temperature waste heat is quite abundant in industrial processes. However, only a few processes allow for the sensible use of waste heat with a temperature level significantly below 100 °C. A plant concept is therefore currently being validated under realistic laboratory conditions, which allows gases to be compressed to an industrially relevant pressure level using low-temperature waste heat. The principle exploits the volume increase that occurs during the melting of a phase change material (PCM) such as paraffin and, thus, converts heat directly into mechanical energy. In suitable industrial environments, this might replace electric compressor stations and save considerable amounts of electricity. The poster presents simulation data and lab test results on a functional prototype that is currently being tested under application-oriented conditions in the thermal engineering laboratory of Fraunhofer IFAM Dresden.

INTRODUCTION

The technical and economic potential for waste heat utilization (temperature level above 60 °C) amounts to approximately 18 % of the final energy consumption of German industry. However, only a few processes allow for the sensible use of waste heat with a temperature level significantly below 100 °C. Yet it is precisely here that waste heat flows with considerable amounts of energy are available. On the other hand, around 7 % of industrial electricity consumption in Germany is used for compressed air generation. Compressed air is a very expensive form of energy, so that an investment in sufficiently efficient systems for compressed air generation using waste heat can pay for itself within an economically reasonable period of time, despite the associated plant engineering costs. As part of the GasPhas project (Federal Ministry for Economic Affairs and Energy, funding code no. 03EN4063), a plant concept is currently being validated under realistic laboratory conditions, which allows gases to be compressed to an industrially relevant pressure level using low-temperature waste heat. The principle exploits the volume increase that occurs during the melting of phase change materials such as paraffin.

WORKING PRINCIPLE AND EXPERIMENTAL SETUP

The general functional verification of the working principle was provided as part of Fraunhofer's internal research. It is based on a chance result that occurred during laboratory work on PCM heat storage systems, in the course of which the volume expansion of a paraffin-based PCM (Rubitherm RT42, volume jump 14 % at melting point 42 °C) in a phase change heat storage system led to a directed piston-like movement of the storage seal. Following this, the achievable forces were measured on a tensile testing machine and were found to reach a corresponding pressure of around 800 bar. This allows sufficient volume to be compressed per stroke to generate large quantities of compressed air at 10 to 30 bar, for example. The approach has been patented (Andersen et al.). A schematic view of the experimental setup is shown in Figure 1. A vital element of the setup is a highly heat-conducting sintered aluminum fiber structure which is filled with the PCM in order to ensure fast melting and solidification as well as reproducible and economically feasible operation of the compressor.

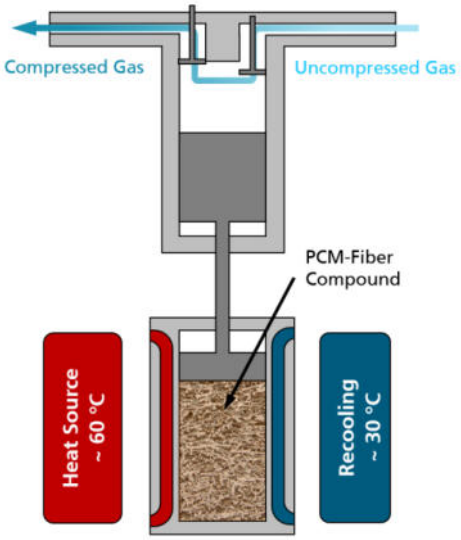


Fig. 1: Schematic view of the experimental setup of the heat-driven compressor.

RESULTS

Figure 2 shows first measurement results, demonstrating that an absolute pressure of 7 bar was reached at a piston displacement of roughly 20 mm. An air volume of 10 times that of the volume change of the PCM was compressed per stroke. Melting and solidification times corresponded well with the simulated time intervals.

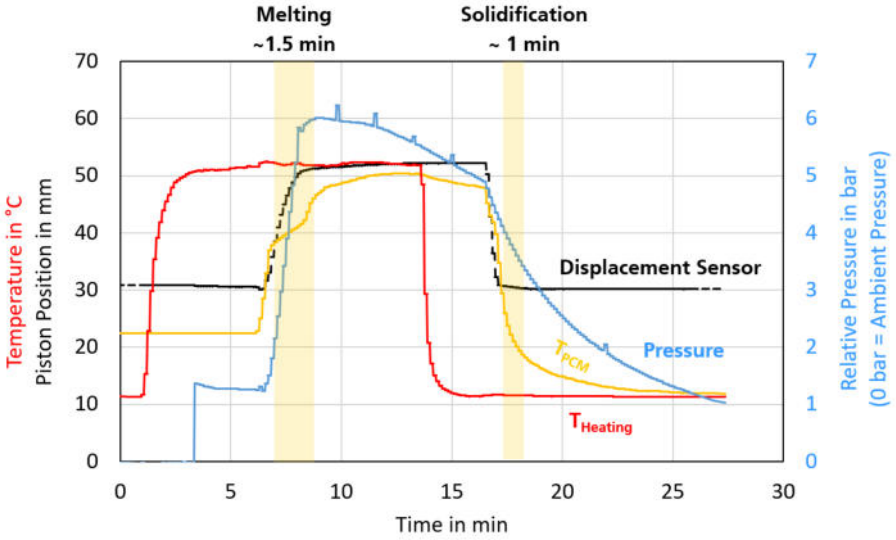


Fig. 1: Temperature, pressure, and displacement readings of the experimental setup.

REFERENCES

Andersen, O., Kostmann, C., Seidel, R., Schlott, A., German Patent DE10 2023 208 568.

CONFERENCE TOPIC

1.06. Excess Heat and Resource Recovery from Low-grade Sources

REPLICABLE BUSINESS CASES FOR THE MULTI-LEVEL INTEGRATION OF LOW-TEMPERATURE DHC GRIDS

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SUMMARY

The project aims to advance the multi-level integration of low-temperature district heating and cooling (LTDE) within the urban energy transition. LTDE differs from conventional systems by relying on green, non-combustion heat sources such as sewage water, shallow geothermal energy, and urban waste heat. These systems typically use heat pumps and enable sector coupling between heat and power. Although demonstration projects have proven technical feasibility, broader deployment requires systemic change and stronger stakeholder awareness. The project therefore seeks to raise awareness and provide actionable business models and implementation strategies for LTDE. A key challenge is developing replicable business cases that create sustainable economic, environmental, and social value. Business models must also remain robust under uncertainties such as electricity prices and demand fluctuations. The project will apply mixed and transdisciplinary methods, with a strong focus on diverse European case studies. It will deliver governance and policy recommendations to support large-scale LTDE integration. Overall, the project will develop sustainable business models, propose flexible implementation strategies, and strengthen stakeholder capacity across Europe.

CONTEXT AND POSITIONING

Low temperature district heating and cooling systems (sometimes referred to as 4th and 5th generation district heating and cooling systems, encompassing ambient networks, – and referred to as low temperature district energy- LTDE in this project) have the capacity to be a cornerstone of this transition and improve the overall resilience of urban energy systems. These systems are combustion-free, based on local resources, and usually interconnect with other urban infrastructures or energy systems (from sewage water to the electricity grid) (Gudmundsson et al., 2022; Hermann et al., 2021). They can support the urban transition especially in less dense areas where conventional district energy cannot be developed, and provide flexibility services to the overall energy system (Backe et al., 2022; Hartmann and Palm, 2022). By being integrated in an overall city-wide planning, they can ensure a fairer energy transition – giving all citizens a chance to connect to an efficient and decarbonized energy grid. The potential of low-temperature heat sources to contribute to the decarbonization of heating in Europe is widely recognized (Figueira et al., 2024). Recent studies estimate that up to 10% of the EU's total heat demand could be met by integrating low-temperature, ambient, and waste heat sources into district heating and cooling networks (ReUseHeat, 2022).

On the other hand, it is evident that cooling needs a much stronger consideration in a future that will be characterized by the massive impact of climate change. Increasing cooling demand traditionally leads to an increasing use of individual air conditioners (AC). However, those units release waste heat from the cooling process into the environment, strongly intensifying Urban Heat Island (UHI) effects (Kikegawa et al., 2014), posing health threats to vulnerable groups, especially older people, the chronically ill and children, and becoming a municipal concern in some major cities. Passive measures, such as shading or green infrastructure can be taken to reduce the trend (Mayrhofer et al., 2023), however, Viguié and his co-authors (2020) indicate that even ambitious strategies for implementing passive measures can only partially offset these negative effects. The

implementation of integrated, multi-level low-temperature district heating and cooling grids can be a key solution for the cooling challenge, since they can harvest the waste heat from cooling and thus reducing the UHI effect. Further on, those systems can store the waste heat via local borehole storages (i.e. regenerating the boreholes) and reuse it in winter for heating. However, there are only a few business models for providing cooling to end users implemented and further investigations is required.

BARRIERS TO IMPLEMENTING LTDE

Despite the known environmental and efficiency gains, implementation remains low. The barriers are not primarily technical, but structural and systemic (Aresti et al., 2024; Hartmann and Palm, 2022; Volkova et al., 2022). These include:

• Lock-in effects from existing high-temperature infrastructure and buildings that require retrofits for low-temperature compatibility.
• The capital-intensive nature of the infrastructures required for LTDE solutions (i.e. decentralized heat pumps, borehole storages, pipes …) together with the adaptation of building side heating (and cooling) systems.
• Historically low prices of natural gas and biomass, which have undermined incentives for adopting alternative sources.
• Procurement, strategic planning and policy frameworks continue to be geared towards centralized and linear infrastructure models, neglecting the value of circular thermal systems and ambient temperature networks.
• Low awareness and knowledge from key actors of the value chain (from policy-makers to energy companies and building owners) to facilitate the multi-level implementation of LTDE.
• Lack of standardized contracts and procedures adapted to the governance of LTDE.

As a consequence, these systems require early coordination among key actors in the value chain — municipalities, utilities, developers, and investors — and call for new alliances (de Bakker et al., 2020) and business models that can spread cost and risk. These require high level of organization and replicable financing models (Qin and Gosselin, 2024; Yao et al., 2024). And even in success cases, more often than none, LTDE develop as bottom-up initiatives. They can end up as islands developing outside the city-wide energy transition strategy and planning instead of being one of its cornerstones. Such development, with exclusion, is not desirable in the energy transition that is targeting fairness.

APPROACH OF THE PROJECT

A centrepiece of the project will be work with case studies across four partner countries (Austria, Switzerland, Denmark and Sweden) focusing on existing building stock. The cases will act as living labs where we can co-create business models and challenge their replicability. For added robustness of our approach, the cases will cover a variety of policy frameworks (depending on the countries and regions they are located in) and a wide range of features, e.g., from privately to publicly operated and owned, from operated networks to planned ones. Each case will have its own focus, e.g., risk analyses (addressed both quantitatively – through a risk register – and qualitatively – via Monte-Carlo simulation), development of financing schemes, focus on procurement practices or design of framework and policy conditions (using a System Dynamics-based tool to assess different strategies to implement and operate DHC infrastructure). Based on desk research, case studies, workshops and interaction with stakeholders, we will generalize our findings to offer a set of replicable efficient sustainable business model specifically for low temperature district energy based on the business model canvas. We will develop recommendations on the policy, governance and regulatory framework at the local, regional, national and European levels to support the implementation of the designed set of business models and the scaling-up of LTDE.

REFERENCES

Aresti, L., Romana Alvi, M., Cecinato, F., Fan, T., Halaj, E., Li, Z., Okhay, O., Poulsen, S. E., Quiroga, S., Suarez, C., Tang, A. M., Valancius, R. & Christodoulides, P., (2024), Energy geo-structures: A review of their integration with other sources and its limitations. Renewable Energy, 230, https://doi.org/10.1016/j.renene.2024.120835

Backe, S., Zwickl-Berhard, S., Schwabeneder, D., Auer, H., Korpås, M. & Tomasgard, A., (2022), Impact of energy communities on the European electricity and heating system decarbonization pathway: Comparing local and global flexibility responses. Applied Energy, 323, https://doi.org/10.1016/j.apenergy.2022.119470

de Bakker, M., Lagendijk, A. & Wiering, M., (2020), Cooperatives, incumbency, or market hybridity: New alliances in the Dutch energy provision. Energy Research and Social Science, 61, https://doi.org/10.1016/j.erss.2019.101345

Hartmann, K. & Palm, J., (2022), The role of thermal energy communities in Germany's heating transition. Frontiers in Sustainable Cities, 4, https://doi.org/10.3389/frsc.2022.1027148

Figueira, J. S., Gil, A. G., Vieira, A., Michopoulos, A. K., Boon, D. P., Loveridge, F., Cecinato, F., Götzl, G., Epting, J., Zosseder, K., Bloemendal, M., Woods, M., Christodoulides, P., Vardon, P., J., Borg, S., P., Poulsen, S. E. & Andersen, T. R., (2024), Shallow geothermal energy systems for district heating and cooling networks: Review and technological progression through case studies. Renewable Energy, 236, https://doi.org/10.1016/j.renene.2024.121436

Gudmundsson, O., Ralf-Roman Schmidt, R.-R., Dyrelund, A. & Thorsen, J. E., (2022), Economic comparison of 4GDH and 5GDH systems – Using a case study. Energy, 238, https://doi.org/10.1016/j.energy.2021.121613

Hermann, E., Nageler, P., Heimrath, R., Mach, T. & Hochenauer, C., (2021), Investigation on sector coupling potentials of a 5th generation district heating and cooling network. Energy, 230, https://doi.org/10.1016/j.energy.2021.120836

Kikegawa, Y., Tanaka, A., Ohashi, Y., Ihara, T. & Shigeta, Y., (2024), Observed and simulated sensitivities of summertime urban surface air temperatures to anthropogenic heat in downtown areas of two Japanese Major Cities, Tokyo and Osaka. Theor Appl Climatol, 117, 1–2, 10.1007/s00704-013-0996-8

Lygnerud K (Editor), Nielsen S, Persson U, Wynn H, Wheatcroft E, Antolin-Gutierrez J, Leonte D, Rosebrock O, Ochsner K, Keim C, Perez-Granados P, Romanchenko D, Langer S, Ljung M. Handbook for increased recovery of urban excess heat, 2022, ReUseHeat Project, Grant Agreement 767429, European Commission, ISBN 978-91-7883-404-4

Mayrhofer, L., Müller, A., Bügelmayer-Blaschek, M., Malla, A. & Kranzl, L., (2023), Modelling the effect of passive cooling measures on future energy needs for the Austrian building stock, Energy and Buildings, 296, 10.1016/j.enbuild.2023.113333Qin, Q. & Gosselin, L. 2024. Community-based transactive energy market concept for 5th generation district heating and cooling through distributed optimization. Applied Energy, 371, https://doi.org/10.1016/j.apenergy.2024.123666

Qin, Q. & Gosselin, L., (2024), Community-based transactive energy market concept for 5th generation district heating and cooling through distributed optimization. Applied Energy, 371, https://doi.org/10.1016/j.apenergy.2024.123666

Viguié, V., Lemonsu, A., Hallegatte, S. & Beaulant, A.-L., (2020), Early adaptation to heat waves and future reduction of air-conditioning energy use in Paris. Environ. Res. Lett., 15, 7, 10.1088/1748-9326/ab6a24.

Volkova, A., Pakere, E., Murauskaite, L., Huang, P., Lepiksaar, K. & Zhang, X., (2022), 5th generation district heating and cooling (5GDHC) implementation potential in urban areas with existing district heating systems. Energy Reports, 8, https://doi.org/10.1016/j.egyr.2022.07.162

Yao, S., Wu, J. & Qadrdan, M., (2024), A state-of-the-art analysis and perspectives on the 4th/5th generation district heating and cooling systems. Renewable and Sustainable Energy Reviews, 202, https://doi.org/10.1016/j.rser.2024.114729

CONFERENCE TOPIC

2.01. Financing and Business Models

EXPERIMENTAL VALIDATION OF AN ALU-TO-ENERGY PROTOTYPE

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SUMMARY:

As part of the EU Horizon Europe project REVEAL, a 4 kW Alu-to-Energy prototype was developed and built. The prototype is part of an innovative seasonal energy storage cycle, in which aluminium oxide is reduced to aluminium at locations and times with abundant renewable electricity, while aluminium is oxidised at locations and times with limited renewable energy, thereby releasing the chemically stored energy. The oxidation reaction of aluminium with water releases heat and produces hydrogen, which can be converted into electricity in a fuel cell. This study describes the process engineering concept of the continuously operable Alu-to-Energy prototype and its quantitative validation. According to efficiency measurements, the conversion efficiency of aluminium to hydrogen is 101.5 ±10.5 % (2σ) and the heat extraction efficiency of the current prototype is 82.3 ±14.3% (2σ). The prototype reached a total reaction power of 3.6 kW and is thus close to the targeted value.
Keywords: ReMEC, MeCRE, Aluminium, seasonal energy storage, Al-water reaction, Al-to-Energy, CHP-unit

INTRODUCTION:

Today, electricity and heat can be generated from renewable energy sources at relatively low cost, and there are several cost-effective short-term storage solutions. However, technologies for the long-term storage of renewable energy remain scarce and expensive. A promising option for seasonal energy storage that is currently being researched is the aluminium-based energy storage cycle. The charging of the storage is achieved by the reduction of oxidised aluminium (Al^{3+}) to elemental aluminium (Al) in central processing plants at locations and times of high availability of renewable electricity. In places and at times with high energy demand and low availability of renewable energy, discharging takes place through aluminium oxidation.
This study describes the findings from the experimental validation of an Alu-to-Energy CHP-unit, developed and built as part of the EU Horizon Europe project REVEAL (www.reveal-storage.eu). The evaluated prototype is designed for a total output of 4 kW (2 kW_{H2} and 2 kW_{th} or 1 kW_{el} and 3 kW_{th}) and is conceptualised for continuous operation. The continuous operation is made possible through periodic and automatic mass transfer between different reaction vessels and periodic automatic removal of solid reaction products, which distinguishes the prototype from earlier developments in this field (e.g. [1], [2]). The three main components of the prototype built are the Reaction Vessel, the Crystallisation Vessel and the Sedimentation Vessel, all of which are filled with a specific amount of 2 M sodium hydroxide (NaOH) solution and are under a defined overpressure (1.5-3.9 bara). In the Reaction Vessel, the Al-water oxidation reaction takes place at a temperature of 70 °C and hydrogen (H_2) and aluminium hydroxide ($Al(OH)_3$) are formed. The reaction heat (2 kW) is extracted from the stirred solution by an internal heat exchanger and the reactants, aluminium and water, are periodically added to the vessel. To prevent accumulation of $Al(OH)_3$ in the Reaction Vessel, liquid with dissolved and solid $Al(OH)_3$ is periodically transferred to the Crystallisation Vessel where any carried over Al granules can react to completion and the crystallisation rate is kept high by stirring. At the same time intervals, liquid is transferred from the Crystallisation Vessel to the Sedimentation Vessel, where the solid $Al(OH)_3$ crystals settle to the bottom. The sediment is

discharged via a valve at the bottom of the Sedimentation Vessel and the NaOH solution is pumped back into the Reaction Vessel to close the cycle. The hydrogen produced may be fed to a water-cooled Fuel Cell Power System (FCPS), where it is converted into electrical (1 kW) and thermal (1 kW) power at nominal power conditions. To compensate for short-term fluctuations in hydrogen production, a Hydrogen Buffer Tank is used.

RESULTS

The quantitative validation of the prototype was carried out at half of the rated power, as this output allows for more stable operation at the current stage of development. Fig. 6 shows the calorific output of hydrogen produced and the heat extracted from the oxidation reaction during an experiment of 6 hours. If the measurement data in the quasi-stationary range (13:00-14.30) is used to calculate the conversion efficiencies, the resulting conversion efficiency for hydrogen production is 101.5 ±10.5 % (2σ) which is in line with small-scale measurements from the chemistry laboratory [3]. However, it became apparent that achieving a steady-state operating condition with the prototype is difficult, as it is challenging to maintain constant levels of process conditions such as NaOH molarity and aluminate concentration. The heat extraction efficiency of the oxidation reaction is 82.3 ±14.3% (2σ) at 50 % part-load conditions, which means that around 20 % of the heat is lost through dissipation to the ambient. Extrapolated to full-load conditions, this loss could possibly be reduced to 10 % if it remains constant in absolute terms whereas the energy turnover doubles at the same time. The efficiency measurements of the coupled process (Alu-to-H_2 & H_2-to-Power), which are also part of this study, are currently being carried out and will allow for a complete energy balance of the prototype.

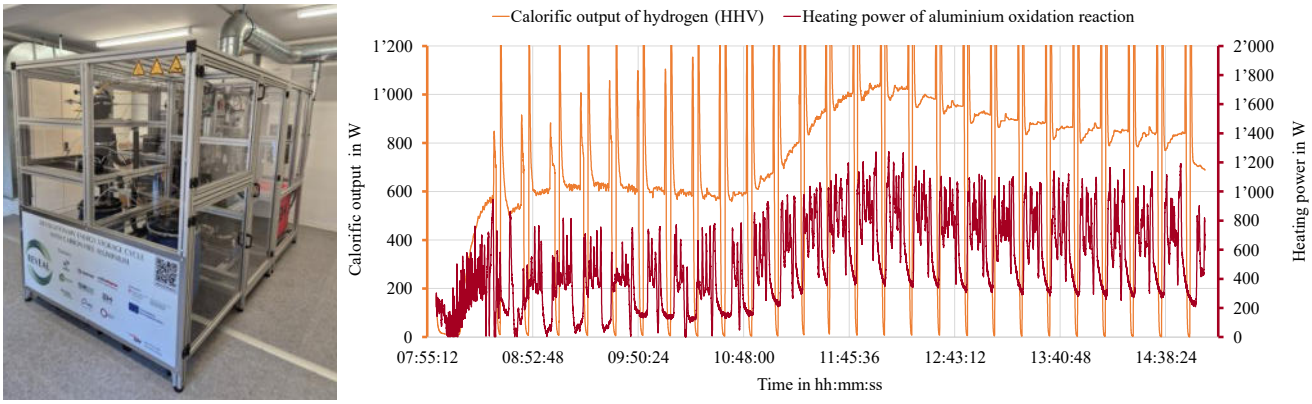


Fig. 15 left.) Photo of the 4 kW_{tot} Al-to-Energy prototype developed and built in the EU Horizon Europe project REVEAL; right.) Calorific output of hydrogen (HHV) and heating power of the oxidation reaction over time during an experiment of 6 hours. Periodic peaks and minima in the measured data are caused by the periodic volume exchange between the different reaction vessels to discharge solid $Al(OH)_3$ from the main reaction vessel.

FUNDING

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REFERENCES

[1] M. Y. Haller, D. Amstad, M. Dudita, A. Englert, and A. Häberle, 'Combined heat and power production based on renewable aluminium-water reaction', *Renewable Energy*, vol. 174, pp. 879–893, Aug. 2021, doi: 10.1016/j.renene.2021.04.104.

[2] D. W. Hurtubise, D. A. Klosterman, and A. B. Morgan, 'Development and demonstration of a deployable apparatus for generating hydrogen from the hydrolysis of aluminum via sodium hydroxide', *International Journal of Hydrogen Energy*, vol. 43, no. 14, pp. 6777–6788, Apr. 2018, doi: 10.1016/j.ijhydene.2018.02.087.

[3] M. Agote-Arán, B. Welte, R. Freeman, N. Mutti, M. Haller, and A. Heel, ‘Al6060 cut wire granules for Al-water reaction: Evaluation of reaction conditions and granule treatments’, *International Journal of Hydrogen Energy*, vol. 117, pp. 430–441, Apr. 2025, doi: 10.1016/j.ijhydene.2025.03.117.

CONFERENCE TOPIC

Next-Generation Technologies for Renewable Energy and Resource Efficiency

CHARACTERISATION AND CONTROL OF SUNLIGHT-DRIVEN PHOTOCATALYTIC PROCESSES IN A SCALED 3 L STIRRED LOOP REACTOR

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SUMMARY

In this contribution a feasibility study on hydrogen production is conducted in a scaled 3 L stirred loop photoreactor (SLPR) using natural sunlight. Thiomolybdate (Mo S)-loaded carbon nitride particles (CN) will be used as a heterogeneous model system for the feasibility studies. To ensure sufficient irradiance incident to

the solar photoreactor the SLPR is coupled to a solar concentrator/reflector developed by AEE INTEC and optimized for $\lambda < 400$ nm tailored to the absorption spectrum of the used light-driven reaction system. In a first feasibility study a solar hydrogen production rate of ≈ 37 µmol·h^{-1} could be demonstrated.

INTRODUCTION

The aim of the conducted project is to demonstrate the feasibility of generating solar hydrogen in a mass transport-intensified SLPR scaled to 3 L. The SLPR concept has already been validated on a 0.5 L scale in a previous studies using Pt-loaded carbon nitride particles (CN_x) for hydrogen production[1]. Since the aim of this study is to demonstrate the technical applicability of immobilised molecular catalysts, a heterogeneous model system for water reduction consisting of CN immobilised molecular thiomolybdate catalyst Mo S (MoS-CN) described by Beranek et al. is being used[2]. The feasibility studies are being carried out and monitored at AEE INTEC. The aim is to systematically investigate the influence of a fluctuating radiation field, as occurs when using natural solar radiation. Since the activity of the MoS-CN_x systems, heavily on the wavelength (high activity in the UV range, low activity in the visible range) of the available radiation and its intensity, it cannot be ruled out that direct solar irradiation of the SLPR is not intense enough in the UV range to be able to detect sufficiently high amounts of hydrogen in continuous operation. This risk is minimised using a solar concentrator/reflector concept developed at AEE INTEC, as the SLPR can be irradiated with concentrated sunlight. The reflector is optimized for focusing radiation in the wavelength range < 400 nm, thus enabling the SLPR to be intensively irradiated in the working range of the MoS-CN_x system. AEE INTEC has a fully equipped test facility for the operation of photoreactors using natural sunlight. Methods for monitoring irradiation conditions (intensity and spectral composition of sunlight) are available at the test facility. In addition, AEE INTEC has extensive expertise in the design and operation of solar concentrators and reflector concepts, which are essential for feasibility studies. Using the Setup for solar hydrogen production depicted in Figure 1, initial feasibility studies enabled solar hydrogen productions rates of ≈ 37 µmol·h^{-1}. In subsequent long-term experiments, the influence of naturally occurring fluctuations in sunlight[3,4] will be investigated and correlated to the observed solar hydrogen production rate.

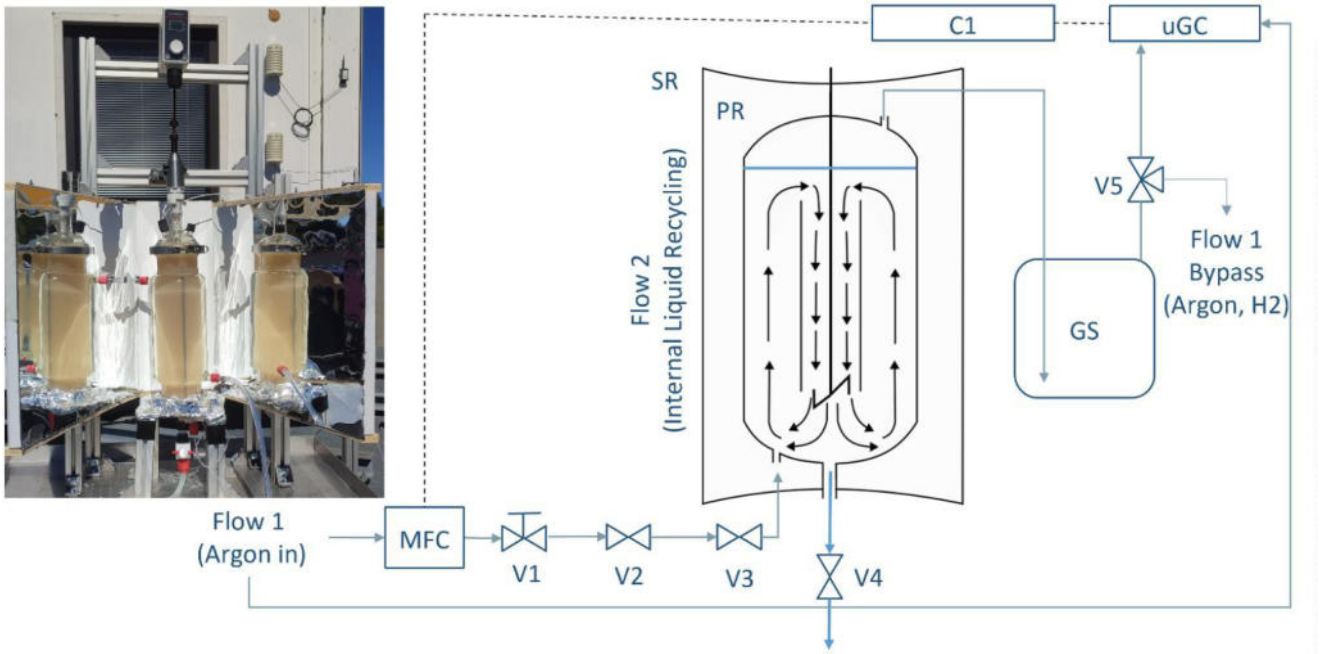


Figure 1: Photograph of the used 3 L SLPR and solar concentrator/reflector concept (left). Flow chart of the setup used for solar hydrogen production (right). PR: Stirred Loop Photoreactor, SR: Solar Reflector, GS: gas scrubber, V1: check valve (gas), V2: one-way valve (gas), V3: one-way valve (gas), V4: one-way valve (liquid exhaust), V5: 3-way valve (gas), uGC: gas chromatograph, C1: computer.

REFERENCES

[1] P. Li, D. Kowalczyk, J. Liessem, M. M. Elnagar, D. Mitoraj, R. Beranek, D. Ziegenbalg, *Beilstein J. Org. Chem.* **2024**,

0, 74–91.

[2] A. Rajagopal, E. Akbarzadeh, C. Li, D. Mitoraj, I. Krivtsov, C. Adler, T. Diemant, J. Biskupek, U. Kaiser, C. Im, M. Heiland, T. Jacob, C. Streb, B. Dietzek, R. Beranek, *Sustain. Energy Fuels* **2020**, *4*, 6085–6095.

[3] J. K. B. Bishop, W. B. Rossow, *J. Geophys. Res. Ocean.* **1991**, *96*, 16839–16858.

[4] E. A. Smith, T. H. Vonder Haar, J. R. Hickey, B. Maschhoff, *Clim. Change* **1983**, *5*, 211–235.

CONFERENCE TOPIC

1.14. Solar-to-X Technologies for Fuels and Chemicals

INVESTIGATION OF DISTRICT HEATING AND COOLING SYSTEMS USING CARBON DIOXIDE AS HEAT TRANSFER MEDIUM

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SUMMARY

Key Words: Carbon Dioxide, CO2, District Heating, District Cooling

This article investigates the economic viability of CO_2 networks and their requirements for a stable energy supply. CO_2 networks are district heating and cooling systems that use carbon dioxide as a heat transfer medium instead of water. While these networks offer several advantages, they are also more complex. For instance, care must be taken to prevent condensation of the vapour line respectively evaporation in the liquid line. To address this issue, the article presents an approach involving a centrally controlled, decentralised buffer storage tank.
The economic analysis also yielded promising results. The best results were achieved with a combined heating and cooling supply using a lake as the energy source. When there is simultaneous demand for heating and cooling within the network, the CO_2 system can exploit all its strengths. In addition to that, promising use cases were also identified for its application as a pure cooling network.

INTRODUCTION AND SYSTEM DESCRIPTION

Climate change is leading to a steady increase in cooling demand in many parts of Europe. In Austria for example the number of days over 30°C has doubled to tripled in recent decades [GeoSphere Austria, 2022]. Installing
efficient cooling systems is particularly challenging in inner-city areas characterised by existing buildings. A pipe-based combined heating and cooling supply using classic four-pipe systems is often not economically viable, resulting in many cases in the use of inefficient split air conditioning units. The CO_2 networks concept examined
in this article could be a good alternative for supplying low-emission energy to consumers in dense urban areas. CO_2 networks are district heating and cooling networks in which carbon dioxide is used as a heat transfer medium instead of water. As shown in figure 1 on the left side, the basic network consists of a vapor and liquid line. Due to the low network temperatures of about 15°C free cooling can be provided for air conditioning by evaporating liquid taken from the liquid line and releasing it in the form of vapor to the vapor line. If lower temperatures are needed, decentralized heat pumps can be used to lower the temperatures further. In heating operation, vapor is taken out of the vapor line, condensed in a condenser-evaporator of the cold side of a heat pump and then released
in the liquid line. Heating and cooling at the same time (at different consumer stations) is possible as well. This
implies that the flow can go in both directions depending on the relative ratio between cooling and heating duties,
and a central plant balances the loads. Another advantage of CO_2 networks is that uninsulated pipes with relatively small diameters can be used. The challenges lie in the complexity of the system and the high pressures (approx. 0 bar) in the pipes.
These kinds of networks are still at a very early stage of development. As part of the ongoing project CO2inloop,

research was conducted into the economic viability of such CO_2 networks and the requirements for a stable energy

supply.

METHOD

For the investigations described in this article, a small network comprising five consumers was modelled using Aspen HYSYS simulation software. The simulations were used to determine the dimensions of essential components, such as pipe diameters, and to identify a suitable control strategy that includes fail-safe measures to ensure a stable energy supply despite the network's increased complexity. A key focus was on implementing a system to prevent unintended condensation of the vapour line respectively evaporation in the liquid line. This can occur due to the energy input from the ground at times when no energy is consumed or heating and cooling demands cancel each other out in (parts of) the network. This issue could be resolved by adding a decentralized buffer storage tank, similar to an additional transfer station, which is centrally controlled to prevent standstills in the pipes. The storage tank can also be used for peak shaving, which partially offsets the additional investment. To assess the system's economic viability, several use cases were defined, covering different applications, and the system was compared with conventional district heating and cooling networks. The distinction was made between a network dedicated to either heating or cooling, and a network providing both simultaneously. Additionally, the study examined which energy sources would be most suitable for a CO_2 network. The use of 'free' energy sources (river, lake,..) was compared with a connection to an existing conventional heating network

RESULTS

The economic analysis yielded promising results. The best results were achieved with a combined heating and cooling supply. When there is simultaneous demand for heating and cooling within the network, the CO_2 system can exploit all its strengths. It has also been demonstrated that using a free energy source is advantageous and that it makes sense to combine the CO_2 network with a photovoltaic (PV) system. In Figure 1 (right side) this configuration of the CO_2 network was compared to a water-based low-temperature network (5G DEG) and a conventional heating and cooling supply comprising of two separate networks (Conv. DEG) once supplied by a biomass boiler and a cooling machine, and once by a heat pump. While some components are still comparatively expensive due to the early stage of development of CO_2 networks, it is evident that the network is already competitive from an economic perspective.

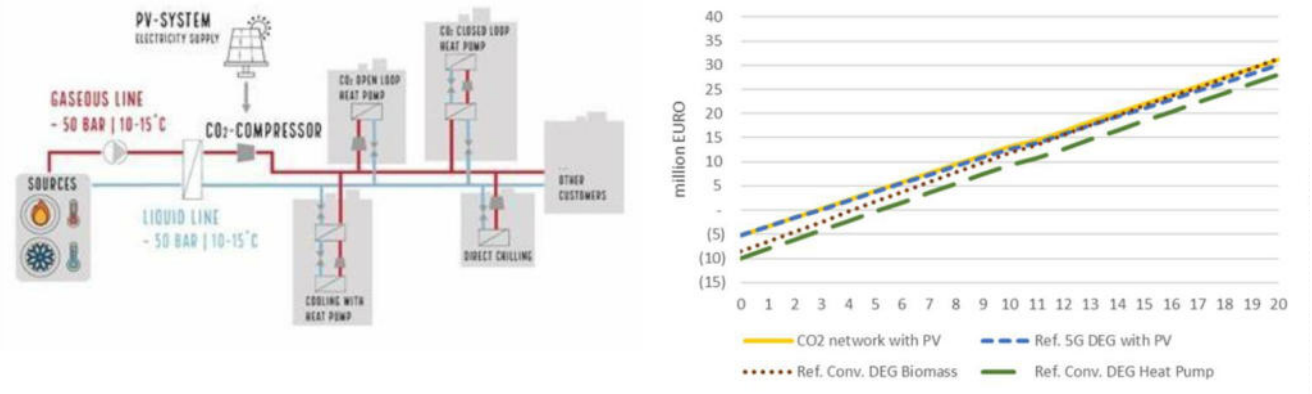


Fig. 1: Schematic system configuration of a CO2 network (left); Net present value curve of a CO2 network for use as a heating and cooling network compared with alternative pipe-based systems for heating and cooling supply (right)

Promising use cases were also found for its application as a pure cooling network, while using a CO_2 network purely for heating is not recommended.

REFERENCES

GeoSphere Austria: Massive Zunahme an Hitzetagen. online, 2022. Link

CONFERENCE TOPIC

Future District Heating and Cooling Solutions

DATA-DRIVEN ALGORITHM FOR TAILORED CCUS FACILITY AND SERVICE PLANNING ACROSS THE LIFECYCLE

INTRODUCTION

The global urgency to mitigate climate change has accelerated the development and deployment of Carbon Capture, Utilization, and Storage (CCUS) technologies. These systems are critical for reducing industrial CO_2 emissions and achieving net-zero targets. However, the design and implementation of CCUS infrastructure remain complex, resource-intensive, and time-consuming. Traditional planning methods often rely on manual calculations, fragmented data sources, and static models, which limit scalability and adaptability across diverse project scenarios.

This study introduces a novel digital solution aimed at automating and optimizing the design and deployment of CCUS infrastructure. The proposed system addresses key components such as capture plants, pipeline networks, compressor systems, and storage facilities. By integrating advanced mathematical modelling, data-driven algorithms, and domain expertise, the solution enables rapid, precise, and scalable infrastructure planning tailored to specific project parameters.

OBJECTIVES AND SCOPE

The primary objective of this research is to develop a comprehensive digital platform that supports end-to-end CCUS infrastructure design. The system is designed to:

- Automate the sizing and configuration of critical CCUS assets.
- Integrate measurement, monitoring, and verification (MMV) planning across all lifecycle phases.
- Adapt dynamically to user-defined inputs and evolving project conditions.
- Ensure regulatory compliance and environmental integrity.

The scope of the solution encompasses the full CCUS lifecycle, including pre-injection planning, active injection operations, and post-injection monitoring. It is applicable to a wide range of industrial sectors and geographic regions, making it a versatile tool for global decarbonization efforts.

METHODOLOGY

The digital framework employs a combination of mathematical models, optimization algorithms, and expert rules to process user-defined inputs. These inputs include:

- **Facility size and CO_2 volumes**: Determines the scale of capture and storage requirements.
- **Geographic and geological data**: Influences pipeline routing, compressor specifications, and storage feasibility.
- **Operational parameters**: Includes pressure, temperature, flow rates, and injection schedules.

Using these inputs, the system generates tailored recommendations for:

- **Capture plant design**: Optimal sizing based on CO_2 throughput and energy efficiency.
- **Pipeline network configuration**: Flow rate calculations, distance optimization, and material selection.
- **Compressor system design**: Pressure requirements, transport efficiency, and redundancy planning.
- **Storage capacity estimation:** Geological suitability, injection rates, and long-term containment strategies.

In addition to asset design, the system defines the scope and structure of MMV services. This includes:

- **Pre-injection monitoring**: Baseline data collection and risk assessment.

- **Active injection monitoring**: Real-time data integration from sensors and SCADA systems.
- **Post-injection verification**: Long-term surveillance and regulatory reporting.

The integration of MMV planning ensures that each phase of the CCUS lifecycle is supported by robust data and analytics, enhancing transparency and accountability.

RESULTS AND OBSERVATIONS

The implementation of the digital solution has demonstrated several key benefits:

- **Efficiency**: Infrastructure planning cycles are significantly shortened, reducing manual effort and accelerating project timelines.
- **Cost-effectiveness**: Optimized asset sizing and configuration minimize capital and operational expenditures.
- **Precision**: Tailored recommendations ensure that each component aligns with project-specific goals and constraints.
- **Compliance**: Built-in regulatory checks and environmental safeguards support adherence to local and international standards.
- **Adaptability**: The system responds dynamically to changing inputs, allowing stakeholders to refine plans as new data becomes available.

Case studies and simulations have shown that the platform can reduce planning time by up to 60%, while improving accuracy and consistency across project components. The integration of MMV planning within the same platform further enhances operational reliability and stakeholder confidence.

NOVELTY AND CONTRIBUTION

The novelty of this work lies in its holistic approach to CCUS infrastructure design. Unlike traditional methods that treat asset sizing and MMV planning as separate processes, this solution integrates both within a unified digital environment. Key innovations include:

- **End-to-end automation**: From initial design to post-injection monitoring, the system supports the entire CCUS lifecycle.
- **Customizable algorithms**: Recommendations are tailored to specific project parameters, enabling flexible deployment across diverse scenarios.
- **Unified platform**: All components—capture, transport, compression, storage, and monitoring—are managed within a single digital interface.
- **Scalability**: The system can be applied to small-scale pilot projects or large industrial deployments, supporting global CCUS adoption.

This integrated approach represents a significant advancement in CCUS planning, offering a scalable and adaptable solution that aligns with long-term carbon management strategies.

CONCLUSION

As the world moves toward aggressive climate targets, the need for efficient and scalable CCUS solutions becomes increasingly urgent. This study presents a digital framework that automates infrastructure design and integrates MMV planning, offering a transformative approach to CCUS deployment. By leveraging data-driven algorithms and domain expertise, the system empowers stakeholders to make informed decisions, optimize resources, and ensure regulatory compliance.

The proposed solution not only accelerates project timelines but also enhances the reliability and effectiveness of CCUS operations. Its adaptability to evolving project conditions and integration of lifecycle support make it a valuable tool for advancing global decarbonization efforts.

AUSTRIA IN IEA ES TASK 46: APPLICATION-ORIENTED SELECTION OF ENERGY STORAGE SYSTEMS

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SUMMARY

Energy storage technologies are essential for the transition towards a decarbonised, flexible, and sector-coupled energy system. While numerous storage technologies are available, their deployment is often hindered by the lack of structured, application-oriented evaluation approaches. Existing methodologies predominantly assess storage technologies based on intrinsic characteristics rather than system-specific requirements, leading to suboptimal implementation pathways. The IEA ES Task 46 [1] “Application-Oriented Selection of Energy Storage Systems (AppES)” addresses this gap by introducing a novel, demand-driven framework for the systematic selection and prioritisation of energy storage solutions. The approach is based on the development of a harmonised KPI framework, a cross-sectoral match-making matrix linking applications and storage technologies, and a multi-criteria evaluation methodology. A central component of the task is the structured collection and analysis of international best-practice examples, enabling validation of the methodology and identification of replicable solutions. The results provide a robust decision-support framework for stakeholders, enabling improved investment decisions, enhanced system efficiency, and accelerated deployment of storage technologies in line with climate targets.
Keywords: energy storage, application-oriented assessment, KPIs, match-making

INTRODUCTION AND OBJECTIVES

The transformation towards a climate-neutral energy system requires a restructuring of energy supply and demand. Increasing shares of renewable energy sources, particularly photovoltaics and wind power, introduce variability and require new forms of system flexibility. Energy storage technologies are essential in this context, as they enable the temporal decoupling of energy generation and consumption, enhance system stability and facilitate sector coupling. In Austria, this challenge is particularly relevant due to the structural characteristics of
the energy system. A significant share of final energy demand is associated with heating and cooling, which requires storage solutions across different temporal scales, ranging from short-term balancing to seasonal storage.

Storage technologies therefore play a crucial role not only in the electricity sector but also in thermal energy systems, where they contribute to the efficient integration of renewable energy and waste heat. Despite this importance, current approaches for selecting storage technologies are often technology-driven and do not sufficiently account for application-specific requirements. This leads to suboptimal system configurations and limits the effective deployment of storage solutions.

IEA ES Task 46 addresses this gap by introducing an application-oriented perspective, focusing on the question:

Which storage technology fulfils a specific application most efficiently regarding technical, economical and systematical aspects?

FRAMEWORK CONDITIONS AND RELEVANCE FOR AUSTRIA

Recent analyses [2] of the Austrian energy system highlight the central role of storage technologies for achieving climate targets and ensuring system stability. In particular, the heat sector represents a major field of application, as it accounts for a substantial share of final energy demand and offers significant potential for the integration of renewable energy through storage solutions. Storage technologies in Austria must therefore address a wide range of temporal requirements, from short-term flexibility in electricity systems to long-term and seasonal storage in thermal networks. Thermal energy storage plays a key role in this context, enabling the efficient utilisation of solar thermal energy, industrial waste heat and excess renewable electricity through sector coupling approaches such as power-to-heat. At the same time, decentralised storage solutions, including building-integrated thermal storage and distributed electrical storage systems, contribute to reducing peak loads and alleviating pressure on energy infrastructure. This highlights the need for a system-oriented perspective that considers storage not as an isolated technology, but as an integral component of a flexible and interconnected energy system.

These developments highlight the need for methodologies that allow for a systematic assessment of storage technologies in relation to specific applications. The ongoing work within Task 46 aims to contribute to this need by developing an application-oriented evaluation framework that reflects the complexity of real-world energy systems.

APPLICATION-ORIENTED ASSESSMENT APPROACH AND RESULT DISCUSSION

The methodological approach within Task 46 is currently being developed and is based on a structured linkage between application requirements and storage technology characteristics. The work builds on the assumption that the suitability of storage technologies can only be assessed in relation to specific applications and system contexts.

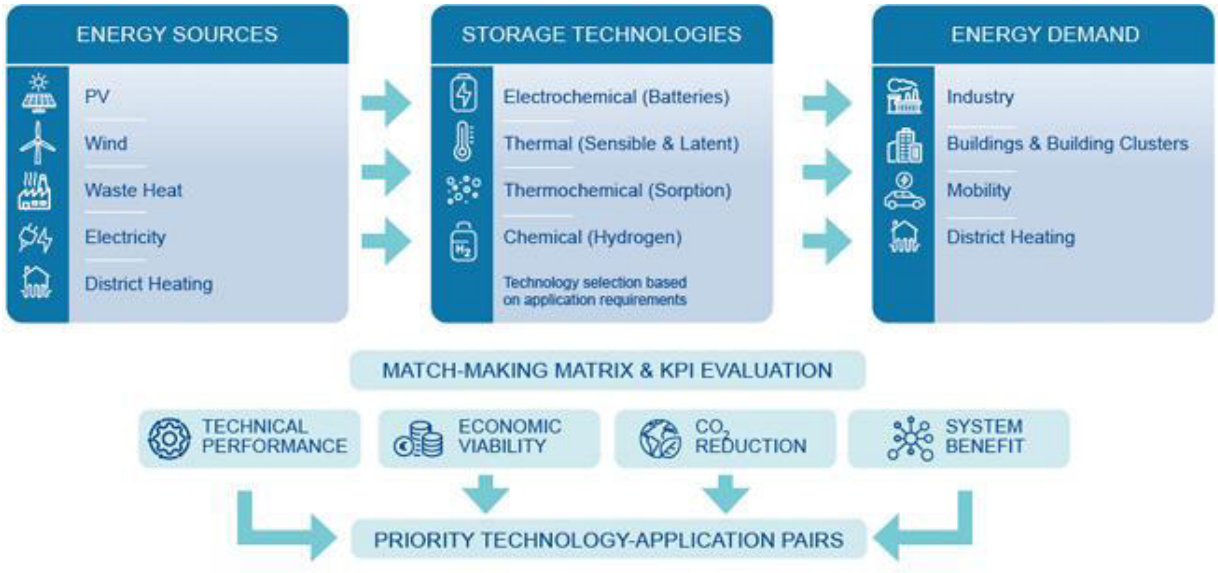


Figure 1: Application-oriented assessment approach

As part of the ongoing work, application cases are being identified and characterised across different sectors, including industry, district heating and cooling, buildings and mobility. These applications are described in terms
of parameters such as energy demand, temporal profiles, temperature levels and system integration requirements.
In parallel, a harmonised set of key performance indicators is being developed to describe storage technologies. These indicators aim to capture technical, economic, environmental and system-related aspects and to enable a consistent comparison across technologies and applications. A central element of the methodology under development is the match-making matrix, which is intended to link application requirements with storage technology characteristics. This matrix is being designed to support the identification of suitable technology application combinations and to provide a transparent basis for their evaluation. Furthermore, a multi-criteria evaluation approach is being elaborated, with a particular focus on CO_2 emission reduction as a key indicator, complemented by economic and system-related criteria. This evaluation framework is expected to enable the prioritisation of technology–application pairs based on their overall system contribution. The methodology is being continuously refined and validated through the collection and analysis of international best-practice examples. These case studies are expected to provide empirical insights into the performance of storage technologies under real-world conditions and to support the transferability of the developed approach.
Initial insights in the Task 46 indicate that the suitability of storage technologies is mainly dependent on the specific application context. Different technologies appear to offer advantages depending on temporal requirements, energy forms and system integration conditions.
Battery storage systems are being analysed primarily in the context of short-term flexibility and grid-related applications, where their fast response times are particularly beneficial. Thermal energy storage systems are being
investigated for their potential in district heating and industrial applications, especially in relation to the integration of renewable heat and waste heat. In the Austrian context, the relevance of thermal storage is of particular interest due to the importance of the heat sector. Ongoing analyses are exploring the role of both large scale and decentralised thermal storage, thermochemical storage and chemical storage solutions in supporting system flexibility and decarbonisation.
Further work is required to systematically evaluate these application-specific characteristics and to derive robust
conclusions regarding optimal technology–application combinations.

IMPACT AND AUSTRIAN CONTRIBUTION

The Austrian consortium is actively involved in the ongoing development of the methodological framework and contributes to several key aspects of the task. This includes the collection and analysis of best-practice examples,
the development of evaluation approaches and the integration of national case studies into the international context. The partners contribute complementary expertise in techno-economic analysis, system modelling and storage technology development. This interdisciplinary approach supports the development of a comprehensive and application-oriented framework. Through its involvement, the Austrian consortium also aims to facilitate the
transfer of knowledge between the international task and the national energy system context, thereby supporting the implementation of storage solutions in Austria.

REFERENCES

[1] IEA TCP Application-oriented selection of energy storage systems – AppES, https://iea-es.org/task-46/

[2] energy innovation austria (2025): Speicherlösungen für die Energiewende – Forschung und Technologieentwicklung in Österreich, Ausgabe 3/2025

ACKNOWLEDGEMENT

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PROMOTING INDUSTRIAL SYMBIOSIS IN A PORTUGUESE INDUSTRIAL PARK THROUGH CARBON CAPTURE AND UTILISATION

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SUMMARY

A circular economy can be promoted by processing or sorting residues to increase their value and enable reuse or sale. In this study a model developed with Pyomo is used to identify and quantify potential industrial symbiosis, which fosters material exchange between enterprises. The model examines all feasible exchanges, providing decision-makers with strategies to optimize residue management. It is applied to the largest industrial park in Portugal. The results show that a proposed industrial plant for producing methanol from CO2, could potentially reduce direct emissions by 335,560 tons annually. Collaboration between local enterprises, supported by strategic investments, demonstrates significant potential for reducing emissions and improving environmental outcomes in this industrial region.

INTRODUCTION

While industries typically prioritize profit through efficient production, they must also consider environmental and social impacts. Many industrial processes generate residues that are often discarded, even though sorting can increase their value and enable sale instead of disposal [1]. This paper introduces a Pyomo-based model to identify and quantify potential industrial symbiosis, evaluating various carbon capture, utilisation, and storage (CCUS) processes, with TRL of 9, to enhance resource sharing between enterprises.

METHODOLOGY

A network flow is modelled to establish as much exchanges as possible [2], to achieve this, a mixed integer linear program was developed. The objective function maximises materials exchanged between enterprises, eq. (7).

$$\max Total_{EM} \tag{7}$$

In eq. (7), $Total_{EM}$ represents the sum of all exchanged material between enterprises. The three parcels of possible exchanges are presented in eq. (8)

$$Total_{EM} = \sum_{n}\sum_{j}\sum_{i}\sum_{n'} EM_{n,j,i,n'} + \sum_{n}\sum_{j}\sum_{i}\sum_{n''} EM_{CCU_{n,j,i,n''}} + \sum_{n''}\sum_{j}\sum_{i}\sum_{n} EM_{CCUR_{n'',j,i,n}} \tag{8}$$

$EM_{n,j,i,n'}$ represents the exchanged material with the indices: n and n', donor and receiver enterprises, j, category, and i, material. Each material is categorised according to its role in each enterprise, these are: resources (category 0), products (category 1), subproducts (category 2), and residues (category 3). $EM_{CCU_{n,j,i,n''}}$ is obtained similarly to $EM_{n,j,i,n'}$, the main difference is that it evaluates the possibility of establishing a CCUS technology in the park. Furthermore, $EM_{CCUR_{n'',j,i,n}}$ determines the material exchanged from the CCUS unit to the existing local enterprises. An LCA is also carried, both before and after the optimisation of the IP, as this allows us to have a clear picture of how the new industrial park configuration is improving the environmental performance of the IP.

CASE STUDY

This study assesses the largest industrial park in Portugal, which encompasses a refinery and a petrochemical plant, as the two largest facilities within the park, all data was gathered from public sources. Several CCUS technologies were considered and evaluated based on models presented in the literature [3], such as, methanol, polyurethane, and salicylic acid production processes (all with TRL 9).

RESULTS

The results obtained show that 21 symbiotic exchanges can be established between the existing enterprises (or already approved projects) in the Sines industrial park, totalising 1,871,308 tons of exchanged materials ($EM_{n,j,i,n'}$). These exchanges are quantified in CO_{2eq}. The largest exchanges are presented in Figure 1.

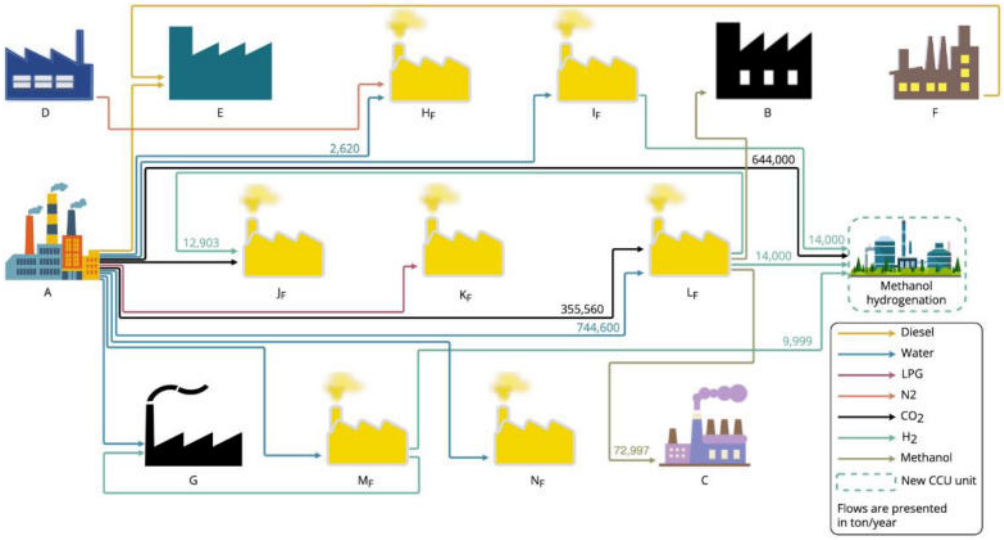


Fig. 1: New IP network configuration with possible symbiosis and respective exchanges.

The model identified the production of methanol as the most effective process for the case study, as methanol is a product that can be consumed by other enter-prises in the park and directly reduces the CO_2 emissions in the park. Establishing a methanol plant utilising CO_2 can reduce the park's CO_2 emissions by 644,000 $tons_{CO2eq}$.

Conclusions

Industrial parks can reduce their carbon footprint by promoting a carbon circular economy through industrial symbiosis, enabling direct CO2 and residue utilization. The implementation of carbon utilization technologies allows achieving annual emissions reduction of 644,000 tonsCO2eq while supporting local methanol consumption, and a total of 1,871,308 tons of exchanged materials. Cooperation between enterprises and their planned investments generates significant regional environmental benefits. Future research should focus on including transportation and indirect emissions.

REFERENCES

[1] Patricio J., Kalmykova Y., Rosado L., Cohen J., Wes-tin A., Gil J., (2022), Resour Conserv Recycl 185.

[2] L. Fraccascia, D.M. Yazan, V. Albino, H. Zijm, (2020), Int J Prod Econ 221.

[3] B. Dziejarski, R. Krzyżyńska, K. Andersson, (2023), Fuel 34.

CONFERENCE TOPIC

1.10. Industrial and Urban Symbiosis

Developing Academic Skills for the Decarbonisation of District Heating and Cooling: Results from Academic Programme Development and Initial Pilot Activities in the Skills4DHC Project

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ABSTRACT

The penetration and decarbonization of District Heating and Cooling (DHC) systems is recognised as a relevant driver of the European energy transition. Beyond technological innovation, rules and regulations and funding opportunities, achieving an effective and lasting transition requires a large and skilled workforce across engineering, design, and installation. Therefore targeted training actions are needed together with the active involvement of a wide range of stakeholders, including system operators, planners, public authorities, policymakers and academia. Without adequately skilled professionals and shared knowledge frameworks, the deployment of low-carbon DHC solutions risks being slow, fragmented and suboptimal.

Within this context, the EU LIFE project **Skills4DHC** aims to strengthen capacities and competences along the DHC value chain by developing innovative, collaborative and practice-oriented training pathways. This contribution presents the first results referred to the Italian context, focusing on three key activities. First, a deep analysis of national training needs related to DHC systems, and their decarbonisation is presented, addressing technological aspects, as well as regulatory and governance challenges. The results have been gathered through a survey campaign among two local and national authorities, two training providers, association of craftsman and national associations. Second, the co-design of innovative training schemes developed is reported: the new training and mentoring schemes are clustered in 3 main programs for white collars, academia and blue collars.

This process is developed in close collaboration with national stakeholders, private companies and universities. The process is enriched by the exchange of best practices and successful experiences among European project partners. This process aims to ensure the relevance, applicability and long-term impact of the proposed educational pathways. Third, the contribution reports on the launch of the first pilot activities implemented in Italy, and the importance of a structured reporting scheme of the main results. The pilot campaign will consist in 4 pilots for white collars, 5 for academia and 3 for blue collars in close cooperation with national stakeholders and institutions.

Preliminary results highlight the value of an integrated approach combining training needs assessment, stakeholder engagement and pilot implementation to bridge existing skills gaps and to effectively support the decarbonisation of DHC systems in Europe.

KEYWORDS

District heating, professional training, Innovative education, Decarbonisation, skills development

TOWARDS SECURE AND TRANSPARENT PEER-TO-PEER ENERGY TRADING

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SUMMARY

The revised draft of the Austrian Electricity Industry Act (ElWG) introduces a legal framework for peer-to-peer (P2P) energy trading, enabling prosumers and consumers to conclude direct energy contracts. To make this form of trading reliable and scalable, both legal and technical structures are required. Within the flagship project *USEFLEDS* (Data Service Ecosystem for the Energy Transition), a P2P trading architecture has been developed that integrates the concept of a data intermediary. Acting under the provisions of the Data Governance Act (DGA), the data intermediary assumes the role of a neutral broker, ensuring secure and transparent exchange of both technical and contractual data. This combination of regulation, interoperable infrastructure, and trustworthy data services lays the foundation for transparent and legally compliant P2P energy trading in Austria. Keywords: peer-to-peer energy trading, legal framework, data intermediary

INTRODUCTION

Peer-to-peer (P2P) energy trading is based on local prosumers who generate renewable energy, thereby enabling decentralized supply. Key factors for its establishment include business models, platforms, and technologies such as cloud and blockchain (Zedan et al., 2023). To achieve a true symbiosis of energy supply, monitoring, and trading, digital systems are essential. Energy trading typically takes place via platforms, whose design determine the range of trading possibilities and enable consumers to find matching partners for P2P trading (Alam et al., 2024). When developing such a digital platform, a holistic approach is required—one that considers both current and future participants in the energy market. This includes different types of aggregators, energy suppliers, necessary data platforms, grid operators, as well as the legal frameworks.

ARCHITECTURE

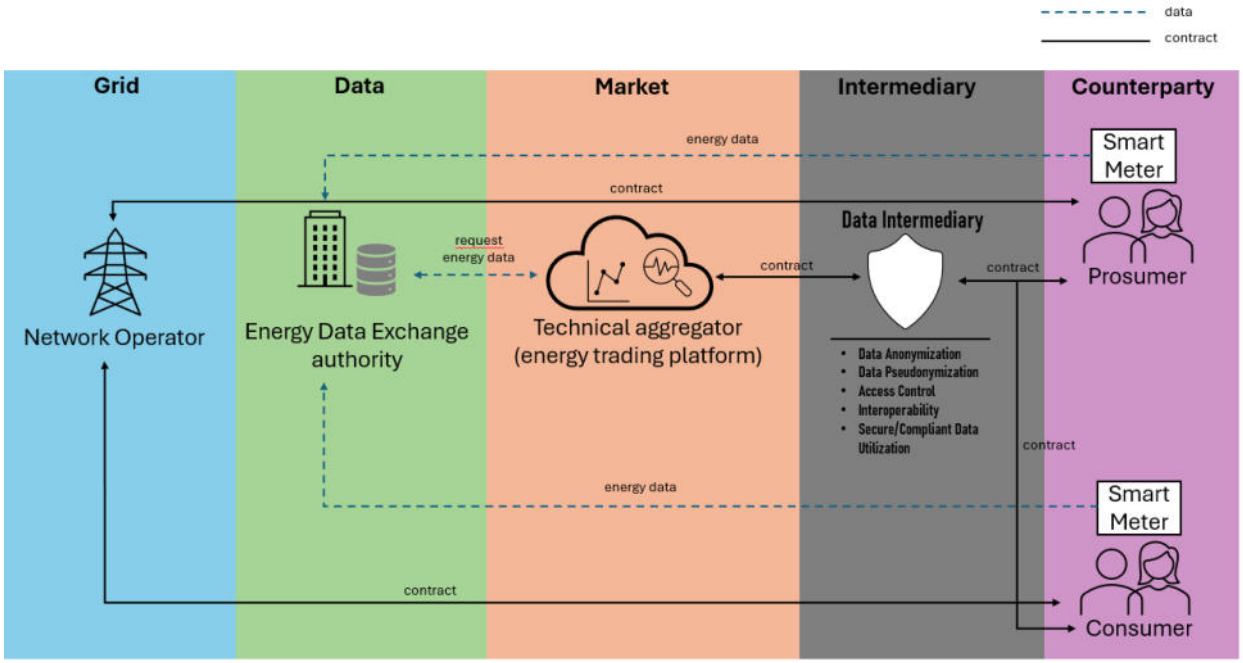
P2P trading as outlined in the ElWG draft depends on existing infrastructure such as the Austrian Energy Data Exchange (EDA), and further requirements. These include, that a producer must generate electricity from renewable sources, usage of smart meters with quarter-hourly values and information on the metering point numbers of both consumers participating in the P2P contract. To help producers and consumers to find suiting P2P trading partners, the architecture of a trading platform using a data intermediary is developed (see Figure 1). The platform relies on a matching algorithm, which identifies buyers and sellers while considering individual factors such as flexibility, grid compatibility, and sustainability.

This approach relies heavily on the secure, fair, and transparent exchange of data between different parties. The Data Governance Act (DGA) provides the legal and organizational framework that ensures data is exchanged securely, fairly, and transparently, which is essential for trust and scalability. Another stakeholder operating under the provisions of the DGA is the data intermediary (Möller et al., 2024). Within our approach (Figure 1), this entity could assume the role of a neutral broker in the (energy) market, ensuring compliance while fostering secure, transparent, and trustworthy data exchange between different actors. Since contracts play a central role in P2P energy trading, the data intermediary may also be of particular importance in this context. By acting as a neutral broker, the data intermediary could facilitate the secure and transparent exchange of contractual data between trading partners, thereby enhancing trust, compliance, and interoperability within the market, highlighting their significance for the governance and enforcement of P2P contractual relationships.

RESULTS

Initial work on the prototype indicates that the integration of structured energy data with stakeholder-specific requirements provides a viable foundation for P2P energy trading. The prototype demonstrates how prosumer and consumption data, once harmonized through standardized data structures, can be securely exchanged and allocated between trading partners. The role of the data intermediary, embedded under the provisions of the DGA, ensures transparent and trustworthy handling of both technical and contractual data.

Figure 59: Overview of P2P architecture with data intermediaries



Preliminary findings suggest that aligning the prototype with existing infrastructures such as the EDA enables interoperability with established market processes. At the same time, the architecture remains flexible enough to incorporate future actors and evolving regulatory requirements. The results highlight the importance of considering both legal frameworks (ElWG, DGA) and technical components (smart meters, allocation methodologies, matching algorithms) in a convergent design.

REFERENCES

Alam, K. S., Kaif, A. D., & Das, S. K. (2024). A blockchain-based optimal peer-to-peer energy trading framework for decentralized energy management with in a virtual power plant: Lab scale studies and large scale proposal. *Applied Energy*, *365*, 123243.

Möller, F., Jussen, I., Springer, V., Gieß, A., Schweihoff, J. C., Gelhaar, J., ... & Otto, B. (2024). Industrial data ecosystems and data spaces. *Electronic Markets*, *34*(1), 41.

Zedan, M., Nour, M., Shabib, G., Nasrat, L., & Ali, A. A. (2024). Review of peer-to-peer energy trading: Advances and challenges. *e-Prime-Advances in Electrical Engineering, Electronics and Energy*, *10*, 100778.

CONFERENCE TOPIC

1.05. Digitalization for Smart, Resilient Energy Systems

FROM BUILDING DATA TO DIALOGUE: LEVERAGING MCP FOR LLM-POWERED ENERGY DATA ANALYSIS

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SUMMARY

This paper presents an architecture for adaptive interpretation of building-level energy data using large language models (LLMs). Local measurements are collected in database and made accessible via a custom Python interface. Through the Model Context Protocol (MCP), both local and external data sources are integrated into a standardized context layer for LLMs. A cloud-hosted LLM (Runpod) consumes this context to provide role-specific insights, ranging from simplified user explanations to detailed technical analyses for facility managers. Initial results show that the approach improves accessibility, adaptability, and integration of heterogeneous data sources compared to static dashboards. Future work will focus on quantitative evaluation, scalability, and user studies.

Keywords: Energy data, Large Language Models, Model Context Protocol, Building energy management

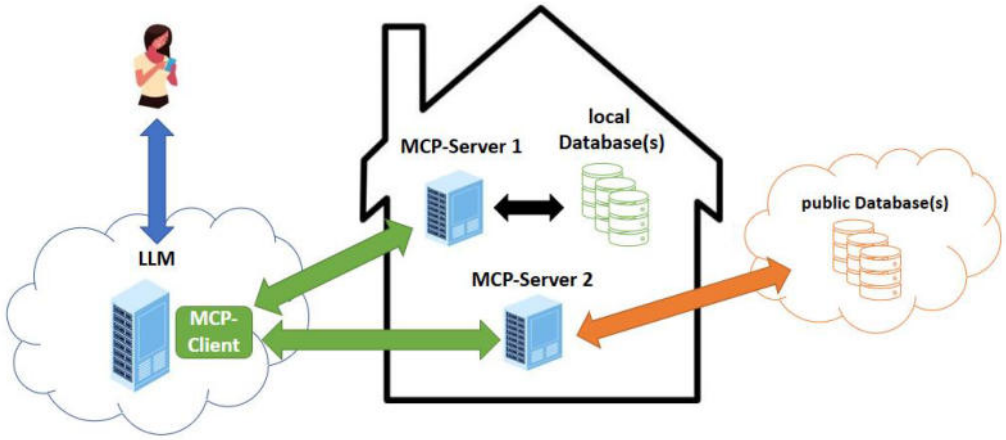
INTRODUCTION

The digitalization of buildings generates increasing amounts of energy-related data, such as electricity consumption, heating demand, and sensor measurements. This data can support efficiency, awareness, and sustainability goals, yet its interpretation remains challenging. Stakeholders, ranging from residents to facility managers and policymakers, require different levels of abstraction: while some prefer simple recommendations, others need detailed technical insights. Conventional dashboards and reporting tools often fail to meet these diverse needs, as they provide static views without adaptive explanations. In contrast, large language models (LLMs) have shown potential as natural-language interfaces to complex data, lowering entry barriers for non-experts while still supporting advanced analysis (Tong et al., 2024; Wang et al., 2025). A key challenge is that raw building data cannot be directly processed by LLMs. Structured, contextualized access is required to produce meaningful results. To address this, we present an architecture that links local and external data sources with LLMs via the Model Context Protocol (MCP) (Anthropic, 2024). Implemented with cloud-hosted LLMs, the system enables target-group–specific interpretation and visualization of energy consumption.

ARCHITECTURE

The proposed architecture is structured into three main layers: data acquisition and storage, context integration, and LLM-based interpretation (Fig. 1). Local energy measurements from the building are continuously collected and stored in a local database. To access the database, a custom Python script (MCP-Server) has been developed, which implements dedicated access functions such as query handling, data aggregation, and error management. In addition to building-specific data, external sources, e.g., public datasets on weather conditions or energy prices, are integrated into the system to provide additional context. The MCP serves as the standardized interface between data sources and the LLM. Each data source is connected through a dedicated MCP server. These servers expose structured subsets of data to the MCP client, which operates within the LLM environment. By using MCP,

the architecture decouples data storage from model access, ensuring flexibility, reproducibility, and the possibility of adding further data sources without modifying the LLM itself (Anthropic, 2024). The contextualized data streams are consumed by the LLM deployed in a cloud environment. For this work, open-source LLMs such as deepseek-v3.1 (DeepSeek, 2024) and gpt-oss (OSS, 2024) are integrated via openweb-ui



(OpenWebUI, 2024), which provides a conversational interface. The LLM is tasked with generating user-specific interpretations of energy data, adapting its output to the target audience.

Fig. 1: Overview of the LLM-MCP architecture

RESULTS

Initial experiments with the architecture indicate that the combination of MCP and LLMs enables effective and adaptive communication of building energy data. When provided with contextualized input, the LLM is capable of producing role-specific interpretations that go beyond static dashboard visualizations. End-users without technical expertise can obtain easy-to-understand explanations of their energy use as well as suggestions on how to optimize their energy consumption. Facility managers and technical staff receive more detailed analyses when requested. Thanks to the MCP-based design, the architecture is not limited to building-level data alone. Public datasets (e.g., weather or tariff data) can be integrated seamlessly and used by the LLM to enrich its explanations. The results suggest that LLMs, when connected to structured energy data via MCP, offer a promising foundation for next-generation energy management systems. They combine the advantages of conversational interaction with the rigor of database-backed context provisioning. Future work will focus on quantitative performance metrics, scalability testing, and long-term user studies.

REFERENCES

Anthropic (2024). Introducing the Model Context Protocol. https://www.anthropic.com/news/model-context-protocol

DeepSeek. (2024). Deepseek-v3.1 model documentation. Retrieved from https://github.com/deepseek-ai

OpenWebUI. (2024). OpenWebUI: A conversational interface for LLMs. Retrieved from https://github.com/open-webui

OSS. (2024). GPT-OSS: Open-source LLM implementation. Retrieved from https://github.com/gpt-oss

Tong, B.-Y., Kuo, T., Lin, C.-Y. (2024). Visualization-oriented Natural Language Interfaces for Grafana Dashboard. International Conference on Consumer Electronics – Taiwan.

Wang, Z., Lin, W., Hu, X. (2025). Self-service Teacher-facing Learning Analytics Dashboard with Large Language Models. Proceedings of the 15th International Learning Analytics and Knowledge Conference.

CONFERENCE TOPIC

Topic 1.02. Building the Future: Smart Energy Infrastructure for the Energy Transition

ENERGIE STEIERMARK

Welcome

Company presentation of Energie Steiermark


Energie Steiermark
Official partner
of a green world.

Key facts

ENERGIE STEIERMARK

Official partner of a green world

and energy services



€ 2.19 billion in sales

€ 113.6 million operating profit (EBIT)
Equity ratio of 42.6%

Electricity, natural gas, heat, hydrogen, broadband & mobility

are the core business areas of Energie Steiermark

2,199

Employees

29 main operating locations

are located in **Styria**. Including outside Austria: Slovakia, Czech Republic, Slovenia, Germany and France

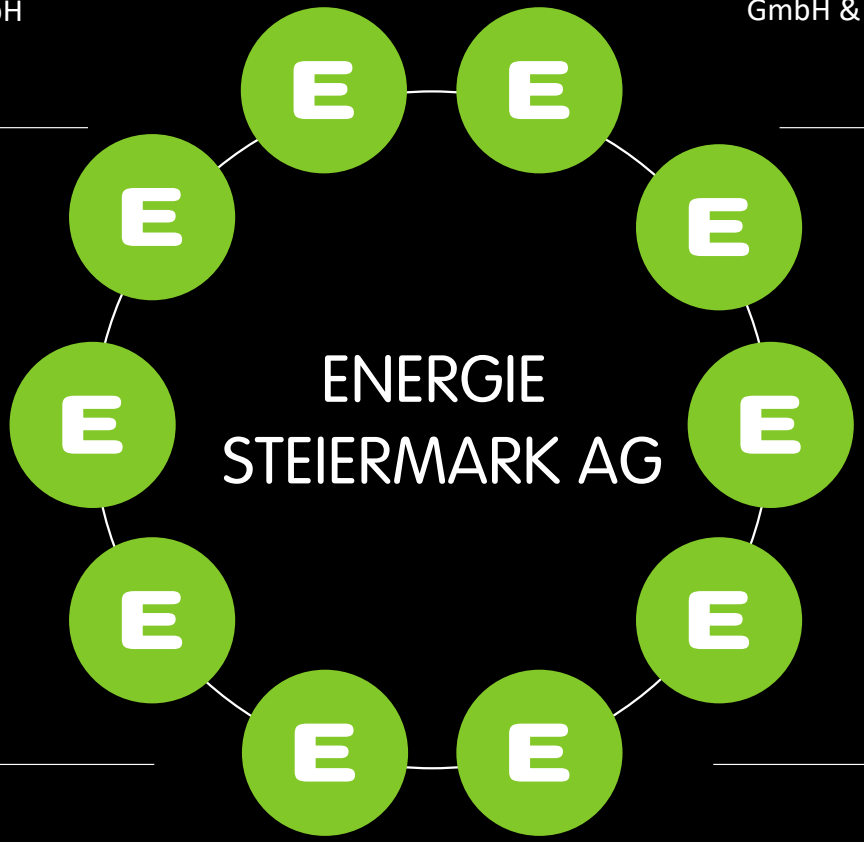
Organisation chart

Energie Steiermark Breitband GmbH

go green energy GmbH & Co KG

ENERGIENETZE Steiermark GmbH

E1 Wärme und Energie GmbH



Energie Steiermark GREEN POWER GmbH

Energie Steiermark WÄRME GmbH

Energie Steiermark KUNDEN GmbH

Energie Steiermark SERVICE GmbH

Energie Steiermark BUSINESS GmbH

Energie Steiermark Wasserstoff GmbH

Important key figures of Energie Steiermark

Type	2024	2023	2022	2021	2020	2019	2018
Sales revenues	2,191.9	2,786.9	2,616.5	1,807.2	1,584.9	1,373.0	1,267.1
Operating result (EBIT)	113.6	150.4	103.2	30.6	73.5	123.0	98.4
Earnings before taxes (EBT)	209.7	198.5	106.5	56.8	94.1	138.4	105.6
Earnings after taxes (EAT)	192.5	160.8	71.9	47.9	66.7	99.4	74.9
Balance sheet total	4,461.6	4,435.5	5,379.9	4,735.1	3,063.8	3,058.4	2,963.1

The strategic business area objectives contribute to the focused positioning as a Styrian energy and decarbonisation partner

Generation

Add 600 MW of renewable energy by 2030



Networks and technology

Integration of 2,000 MW of renewable energy by 2030



Distribution and trading

Sustainable growth to 1 million customers as a leading partner for green energy solutions by 2030



Broadband

Leading alternative broadband provider in Styria by 2030



Sustainability

Climate neutrality by 2040; reduction of GHG emissions by 50% by 2030



Heat

Increase the share of renewables and waste heat in the Greater Graz area to 50% by 2027



Human resources

Strategic skills development as a top employer in the industry



Growth & investments

Expand, optimise and develop strategic partnerships and investments



Innovation

Leading national innovation hub for sustainability by 2025



Energie Steiermark is one of the leading, most sustainable energy infrastructure companies in Austria.

Ownership interest
100% Province of Styria

29 operating locations
in Styria

~380 GWh CO_2-free total production
(wind, PV, water)

More than 1,000 apprentices
Training in Austria's most modern training centre

more than 1,186 public charging points
operated by Energie Steiermark in Austria

Austrian Ecolabel
For sustainable products and services provided by Business GmbH

Best employer
in Styria 2025
(Trend, Statista, Kununu)

Next Incubator
Innovation hub for sustainability

Founding member of the
Green Energy Lab

Establishment of a hydrogen company
June 2025

97/100 points
GRESB Rating result

2,199 employees
in 2025

Certified with the seals of quality
"berufundfamilie" & "equalitA"

Broadband & smart home
Growth outside the core business

Climate neutrality 2024
by 2030: Reduction of GHG emissions by 50%

Green Loan
of the EIB (€ 90 million) as 1st company in Austria (2nd company in the EU)

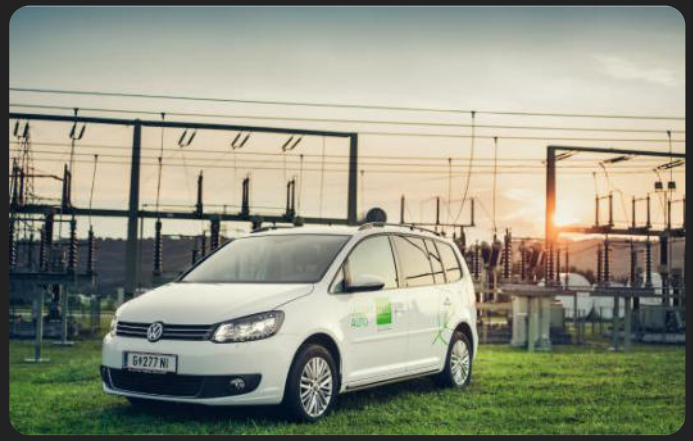
Key facts – renewable energy & grid expansion

>32,000 km
Grid length (system length),
of which

~7,600 km
Overhead lines

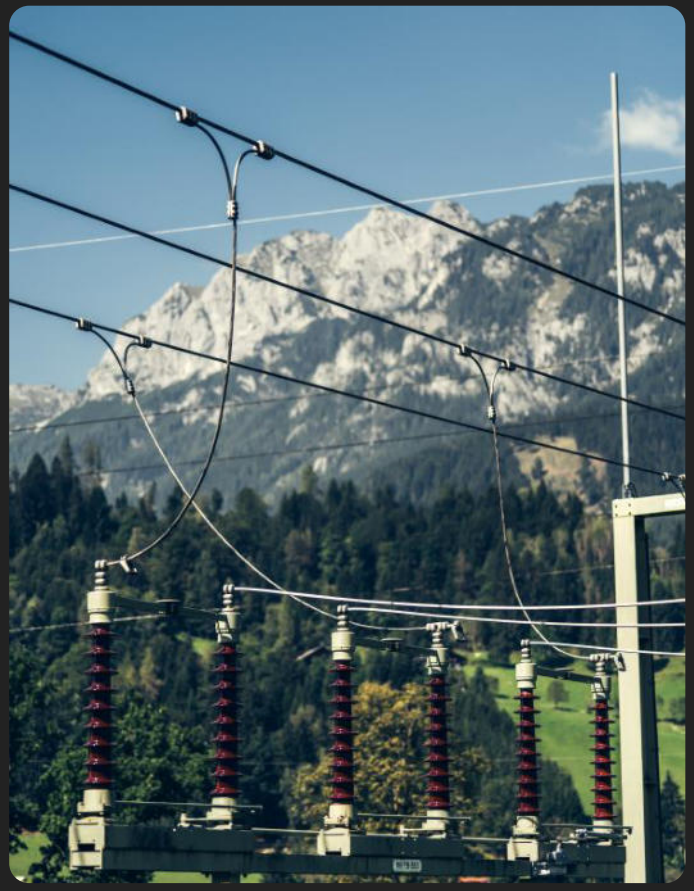
~23,000 km
Cables

~1,900 km
High-voltage power lines



~340
Substations and switching centres

~8,300
own transformer stations



Renewable energy & grid expansion

Investment of € 5.5 billion

in renewable energy projects and grid expansion by 2035



Renewable energy & grid expansion

Integration of 2,000 MW of renewable energy by 2030

Specifically, we are investing around € 1.5 billion in grid expansion by 2030 alone.

In order to ensure security of supply in the future, an investment of around € 200 million is planned for the expansion of the Styrian grid in 2025.



Renewable energy & grid expansion

Integration of 2,000 MW of renewable energy by 2030

Modernising and upgrading our more than 32,000 kilometre-long electricity grid is crucial if we are to be able to "collect" green electricity from decentralised systems at all.



Key Facts – Photovoltaics



Photovoltaics on roof surfaces

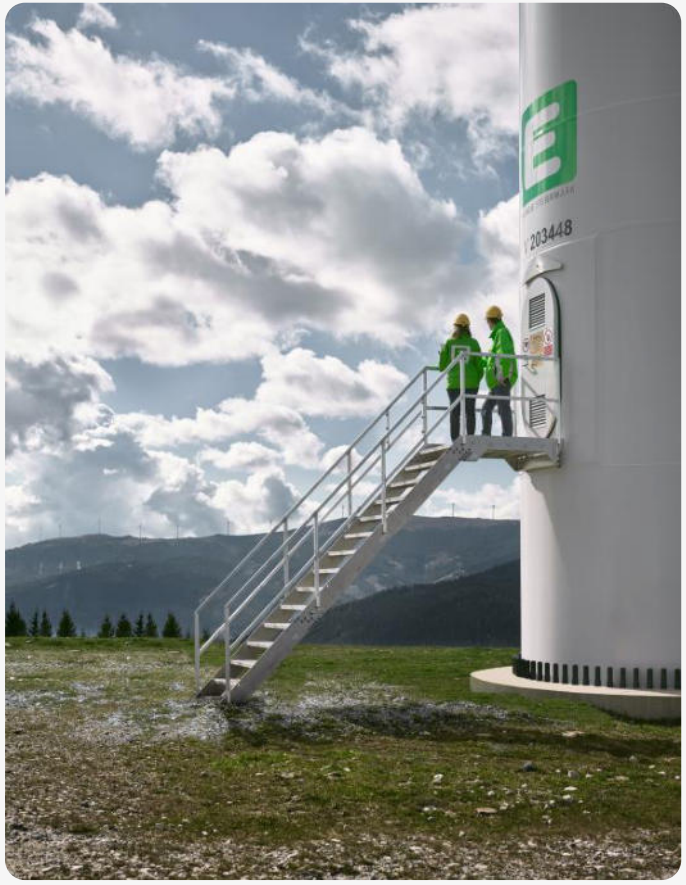
In 2023, around 8,500 kWp and in 2024 around 6,600 kWp of PV capacity was installed on roof surfaces – on commercial and industrial buildings, in municipalities, in agriculture and in residential construction (e.g. Zotter, Unimarkt, Beerenfrost, Planaibahnen, etc.).

15%

Energie Steiermark has set itself the goal of generating solar electricity for 15 percent of Styrian households in the coming years.



Key Facts – Wind power



€ 75 million

have already been invested in wind power



13

more wind projects
are in the project phase

€ 550 million

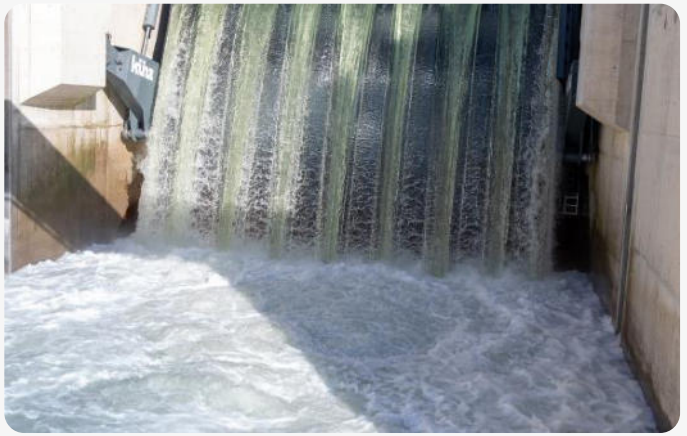
will be invested in future
wind projects

Key Facts – Hydropower



€ 350 million

have already been invested in hydropower



€ 400 million

Investment in future hydropower projects

575 million kWh/year

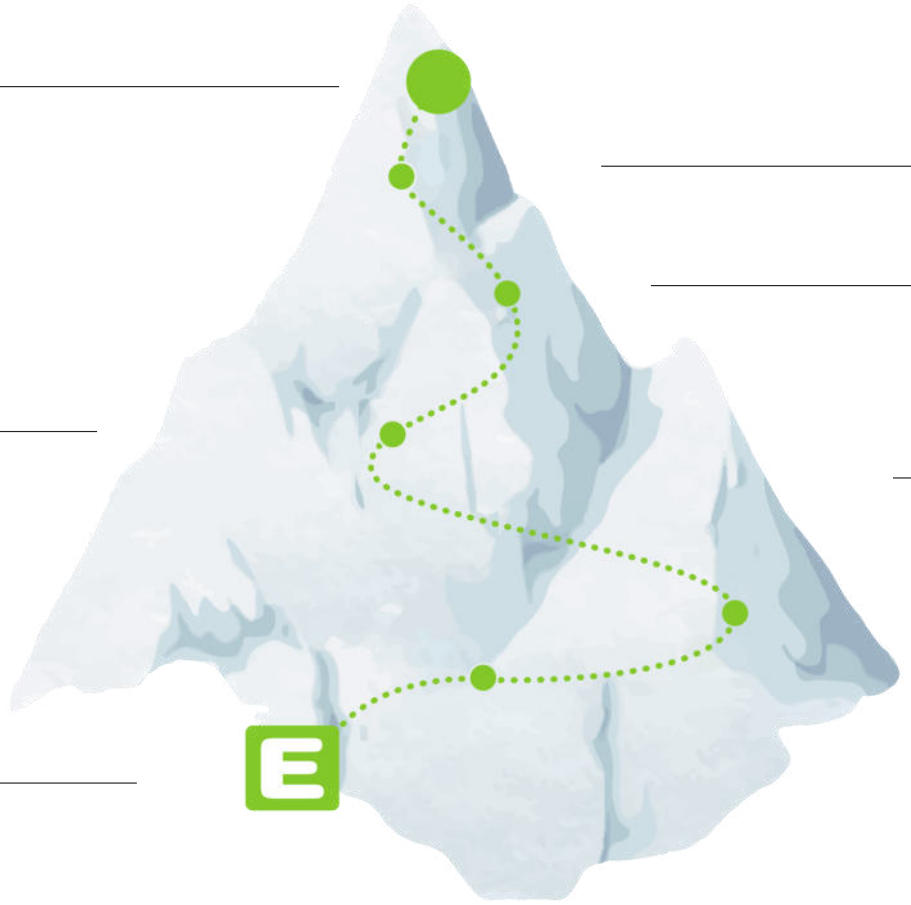
Total electricity generation from hydropower (300 million kWh/year already established)

Our vision

2040 Climate neutrality

2030 Halving of greenhouse gas emissions

2021 Greenhouse gas balance
1.7 million tonnes of CO_2 equivalent



Sale of green gases and 100% green electricity

Emission-free locations and operating sites

CO_2-free electricity grids - green electricity for grid losses

100% green heat generation in the regions

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION
Progress by innovation

GN SEC

Global Network Regional Sustainable Energy Centres

Think globally. Act regionally. Implement nationally.

ISEC 2026

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

GNESEC

UNIDO supports the *creation* and *operation* of **regional sustainable energy centres** since **2010**

The centres are established as specialized institutions of regional economic communities, owned and driven by the region and its member states. They operate under intergovernmental agreements with diplomatic status and receive time-limited support from UNIDO for institution-building and technical program development.

10 OPERATING CENTRES ADOPTED BY **120** **Ministers of Energy and Heads of State**

INFLUENCING THE ENERGY FUTURES OF **~2.2** **billion consumers**

GLOBAL OUTREACH COVERING **40** of 45 **LDCs** **35** of 39 **SIDS**

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

GN-SEC

The GN-SEC Platform facilitates South-South and Triangular Cooperation

Makerspace for joint:

- Coordination
- Learning
- Projects
- Replication
- Upscaling
- Advocacy
- Campaigns
- Tools
- Knowledge
- Fundraising



UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Theory of Change

GNESEC

Vision

To accelerate the energy transition from the regions for the regions, leveraging South-South and triangular cooperation to drive locally owned and sustainable change.

Mission

To reduce institutional, technical, and financial barriers that hinder the development and uptake of integrated and inclusive regional sustainable energy markets.

By addressing market barriers through regional cooperation, policies, regulations, incentives, standards, tools and methodologies



CREATE LOCAL DEMAND
Energy consumers

CREATE LOCAL QUALITY SUPPLY
Energy Businesses

Contribute to national policy objectives and priorities

Contribute to global policy objectives and priorities

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

GNSEC

Activities and services of the regional centers

CREATE SPILL-OVER EFFECTS AND ADDRESS BARRIERS REGIONALLY

- Policy, regulation and guidelines
- Knowledge, analytics & awareness
- Quality infrastructure & skills development
- Investment, business & innovation

PROMOTE THE REGIONAL DIFFUSION AND INDUSTRIALL ROLL-OUT OF INNOVATIONS

- Transferring and developing new technologies, business models and policies
- Testing and demonstration of innovations
- Commercializing, replicating and industrial roll-out of innovations

SCOPE OF SUPPORTED TECHNOLOGIES

- Renewable Energy Solutions (e.g. solar, wind, bioenergy, small hydro)
- Energy Efficiency Solutions (e.g. appliances, cooking, transport)
- Cross-cutting and integrated solutions (e.g. storage, hydrogen, gender and youth)

Broad range of direct beneficiaries and end-use sectors

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

GN-SEC

IMPACT & ACHIEVEMENTS

GN-SEC in numbers

20k+ *PARTICIPANTS*
in sustainable energy events of the centres

5k+ *KEY EXPERTS*
on sustainable energy issues and solutions trained

20+ *TRAINING TOOLS*
developed and disseminated

300+ *MLN USD INVESTMENTS*
mobilized through GN-SEC programs

4 *REGIONAL ENERGY INFORMATION*
systems established

10+ *REGIONAL RE & EE QUALITY STANDARD AND CERTIFICATION SCHEMES*
developed

600+ *ENERGY BUSINESS*
supported

2k+ *REGIONAL DOCUMENTS*
available on GN-SEC platform

50 *NATIONAL RE & EE POLICIES*
and roadmaps developed

ISEC 2026

Wien Energie

Full Power for the Climate!



© Wien Energie | Public

Austria’s leading energy provider

Wien Energie drives the expansion of renewable energy to operate climate neutral by 2040

























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Product Portfolio

Electrical power

Neutral gas

Heating

Cooling

Photovoltaic power

Hydro power

Circular economy

Wind power

Energy services

Energy efficiency

E-mobility

Energy communities

Citizen solar power plants

Research and innovation

Telecommunications

IoT

Hydrogen

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€840m

for **sustainable** heating projects
and circular economy by 2030

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1,000 MW
of Green Electricity Capacity

to be installed by 2030.

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370 MW of District Cooling Capacity

by 2030.

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200 MW

of district heating capacity

from deep geothermal energy

by the 2030s. Providing heat

for up to 200,000 Viennese households!



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