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Impacts of National Energy Price Structures on the Economic Performance of Latent Thermal Energy Storage: A Comparison of Norway, Denmark, and Germany in 2022 and 2023

Summary

Latent thermal energy storage (LTES) can provide end users with cost-saving potential, but its economic value depends strongly on the surrounding energy price framework. Using an identical thermal demand profile and the same technical system setup, this analysis compares Norway, Denmark, and Germany for the years 2022 and 2023 to isolate the effect of country-specific pricing schemes on storage value. The assessment focuses on annual energy cost savings enabled by load shifting and peak demand reduction, while storage size is optimized with respect to the resulting savings and the associated capital cost. The results show that the same storage technology can exhibit substantially different economic performance across countries due to differences in energy price composition, temporal price variability, and tariff structures. The findings underline that techno-economic evaluations of thermal storage should not rely on a single national pricing framework but should explicitly consider and compare multiple country-specific settings.

Keywords: techno-economic optimization, energy storage, thermal energy storage, pricing schemes

Field of application for the findings: Thermal Energy Storage

Addressed audience: Researchers and practitioners in energy storage systems

1. Introduction

Thermal energy storage can increase the flexibility of building and district energy systems by decoupling thermal demand from energy supply over time (Sharma et al, 2009). In particular, latent thermal energy storage (LTES) offers the potential to shift thermal loads and reduce peak demand while maintaining a compact storage volume. From an end-user perspective, this can improve the economic operation of thermal systems by lowering energy procurement costs and, depending on the tariff design, peak-related charges (Kamal et al., 2019).

However, the economic performance of thermal storage depends not only on its technical characteristics, but also on the underlying national pricing framework (Wilczynski et al., 2023). While many techno-economic studies assess thermal storage under specific national or tariff settings, comparative analyses across different national energy prices and tariff structures under otherwise identical conditions remain limited. This study therefore compares Norway, Denmark, and Germany using the same thermal demand profile and technical system setup to isolate the effect of country-specific pricing schemes on storage value.

2. Methodology

2.1. System setup and demand profile

A common electrical and thermal demand profile based on a model office building (ZEB-Lab, 2026; Galteland et al., 2023) is applied to all country cases in order to ensure comparability. The analyzed system, shown in Fig. 1, comprises an electricity grid, a thermal grid based on district heating, an electrical demand, a thermal demand, a photovoltaic (PV) system, a battery storage unit, a heat pump, and a latent thermal energy storage (LTES) unit. The battery and LTES units, whose capacities are determined within the optimization, enable electrical and thermal load shifting, respectively. Both the storages allow higher use of renewable energies, i.e. PV production. The heat pump couples the electrical and thermal domains. Its COP is represented as a function of outdoor temperature with an average simulated COP of 2.7. Both the electricity grid and the thermal grid act as external energy supply options. It is further assumed that the heat pump and the district heating network each have sufficient capacity to meet the full thermal demand independently, ensuring that supply adequacy does not influence the comparative economic assessment. The technical system configuration is kept identical for all country cases so that differences in economic performance can be attributed to the respective national pricing framework rather than to changes in demand or system design.

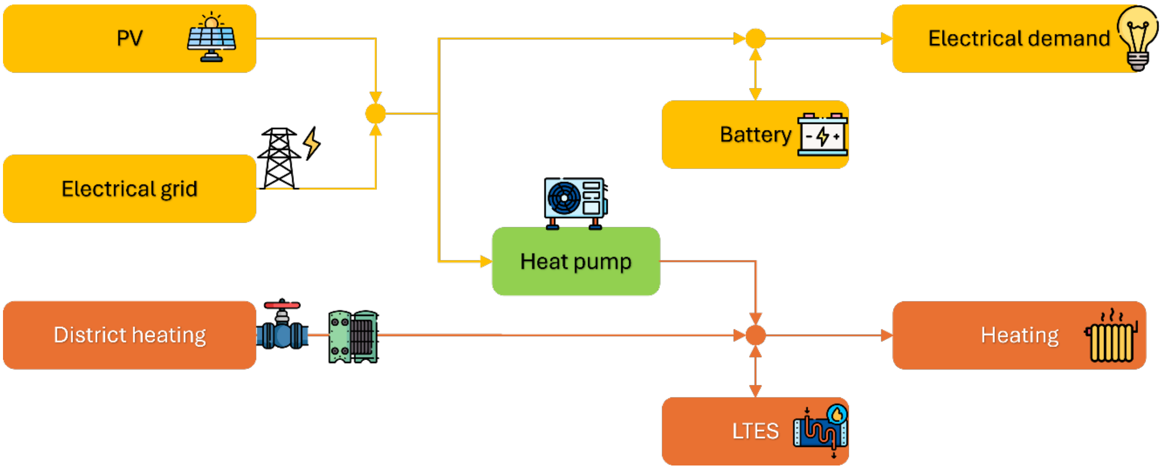

Fig. 1: Simplified scheme of the analyzed system.

2.2. Economic assessment

The assessment focuses on the annual cost-saving potential of LTES from an end-user perspective within the overall multi-energy system. Storage operation is evaluated with respect to variable electricity and thermal energy procurement costs as well as country-specific tariff components. Since the heat pump links electricity consumption to thermal demand, LTES operation can affect both thermal supply patterns and electricity-related peak loads. In addition, the storage size is varied in order to examine the trade-off between achievable cost savings and the associated investment cost, thereby allowing an economic assessment of LTES under different national boundary conditions. Potential economic benefits from downsizing the heat pump capacity were not considered in this study.

2.3. Country-specific input data and model assumptions

The comparison includes Germany, Norway, and Denmark, represented by the bidding zones DE_LU, NO3, and DK2. These cases were selected because they reflect markedly different national energy price and tariff structures while allowing a comparison under otherwise identical technical conditions. The analysis covers the years 2022 and 2023 and uses hourly electricity spot prices. In all cases, country-specific tariff structures are implemented according to the respective national framework. The selected cases differ not only in overall price levels, but also in the composition of end-user energy costs, their temporal variability, and the relevance of tariff components such as demand-related charges. In particular, the Danish case does not include a peak demand fee, which provides a useful contrast to the German and Norwegian cases and supports a clearer distinction between value streams from load shifting and peak demand reduction. For Denmark, the hourly DSO tariff of Tariff Model 3.0 (Energinet DK, 2026) is applied for both years as a harmonized modelling assumption. Specific investment costs are assumed to be 325 EUR/kWh for the battery system, with a lifetime of 15 years, and 100 EUR/kWh for the LTES, with a lifetime of 25 years. In addition, the LTES is modelled with charging and discharging constraints as well as thermal energy losses representative of phase change material-based thermal storage systems.

3. Results and discussion

The results, presented in Fig. 2, show pronounced differences in the economic performance of latent thermal energy storage across the analyzed bidding zones. Although the same technical system configuration and storage concept are applied in all cases, the achievable annual cost reduction varies substantially between DE_LU, NO3, and DK2, as well as between the two analyzed years. While considerable savings are observed in DE_LU and DK2, no relevant economic benefit is obtained in NO3 under the analyzed conditions. These differences are also reflected in the economically optimal TES capacities. In 2022, the optimal capacities are 253.1 kWh for DE_LU, 0 kWh for NO3, and 280.8 kWh for DK2. In 2023, they are 20.1, 0, and 70.8 kWh, respectively, while the combined 2022+2023 assessment yields optimal capacities of 163.2, 0, and 193.8 kWh. The introduction of thermal energy storage also influences the economically optimal battery size. In the economically relevant

DE_LU and DK2 cases, battery capacity is reduced by around 4-16%. Overall, the differences in achievable cost reduction and optimal storage sizing indicate that the business case for LTES is highly sensitive to the local electricity price and tariff structure.

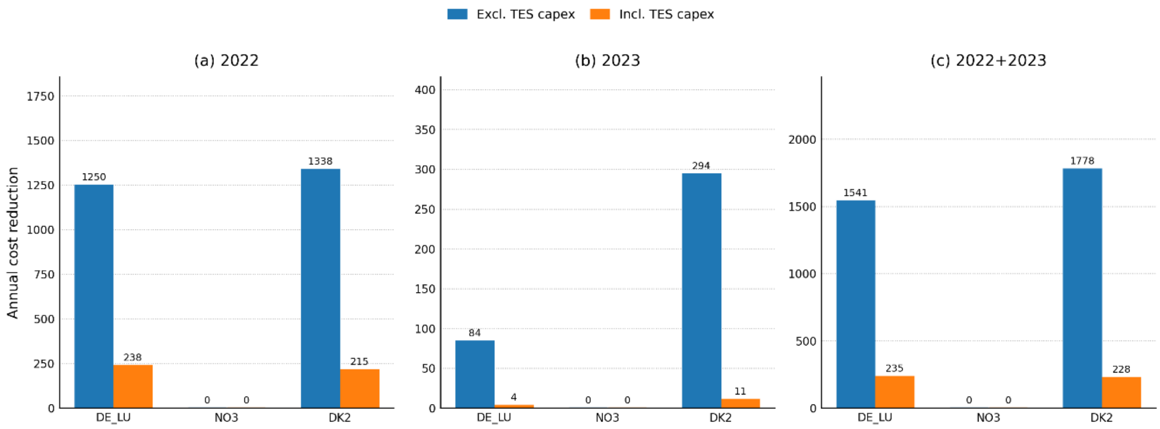

Fig. 2: Comparison of TES-related cost reductions for the bidding zones DE_LU, NO3, and DK2 for (a) 2022, (b) 2023, and (c) the combined period 2022+2023. For each case, results are shown excluding and including TES capital cost.

A notable finding is that the highest savings are achieved in DK2, despite the absence of a peak demand fee in the analyzed Danish tariff structure. This suggests that the economic value of storage in DK2 is driven primarily by temporal load shifting. In particular, the variable tariff appears to contribute significantly to electricity costs during peak-price periods, so that shifting consumption away from these periods yields substantial savings. In contrast, the benefit in DE_LU results from a combination of load shifting and peak demand reduction, highlighting that similar overall savings can arise from different underlying value streams depending on the bidding zone.

The comparison further shows that identical storage concepts can lead to markedly different business cases even when all technical assumptions are kept constant. This is also reflected in the difference between gross savings and net savings after inclusion of TES investment cost. Overall, the results underline that the economic viability of LTES is determined not only by the technology itself, but to a large extent by the bidding-zone-specific price signals and tariff design.

4. References

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