EuroSun2026

DISTRICT HEATING SYSTEMS AS A DEMAND-SIDE FLEXIBILITY RESOURCE

Summary

This paper examines electric flexibility in Germany's district heating sector amid RES volatility and grid pressures. It highlights the strong potential for long-duration flexibility beyond batteries. Realising this potential requires policy and market designs that adequately value long-duration flexibility and provide predictable revenue streams, enabling investment and sector coupling.

Keywords: district heating; Power-to-Heat; PTES; Thermal storage; grid congestion management; flexibility

Field of application for the findings: district heating networks, energy transition policy, grid integration

Addressed audience: district heating system stakeholder, DSO, TSO, policy makers

1. Necessity of Electric Flexibility in the District Heating Sector

The rapid growth of renewable electricity sources (RES) capacity across Europe increases generation volatility. In Germany, the following consequences can be observed:

- Persistent price volatility in the energy market, with negative prices driven by PV feed-in peaks (Day-Ahead: 301 h in 2023, 459 h in 2024, 575 h in 2025 with a peak of -250 €/MWh on 11 May). In extreme cases, this can prevent market clearing and jeopardize system balancing.
- Due to limited grid capacity, grid congestion management is necessary. In Germany in 2024, grid operations faced a congestion management volume of 30.3 TWh (mainly wind curtailment) and roughly €2.8 billion in redispatch costs (SMARD, 2026). In the near future, PV is expected to contribute a significant share of grid congestion.

This challenge makes electricity storage, along with demand- and generation-side flexibility and cross-border transmission, essential for grid stability, security of supply, and a reliable energy transition. RES-generation flexibility is valuable, but without storage it leads to curtailment and higher production costs. Cross-border expansion offers limited relief since neighbouring countries face similar constraints. Storage expansion is currently dominated by batteries, but grid connection capacity limits deployment. Moreover, these storage systems are typically short-term, with discharge durations from 1 to 8 hours.
Against this background, this paper focuses on electric flexibility – mainly on the demand side – in the German district heating sector, which represents a major energy sink and is expected to become increasingly electrified, making it a key lever for system flexibility.

2. Electricity supply of Power-to-Heat units

As part of the transformation of heating networks, substantial portions of heat production -often the main share- will be delivered as power-to-heat (PtH) via heat pumps or electric boilers.

Although Germany´s heat networks have an installed cumulative capacity of about 1.5 GW of electric-boiler capacity (until 2025; own desk research mainly based on company publications) these units are not used for grid flexibility, as they require at least 600 hours per year at strongly negative prices to compete with fossil-based heat generation (Panitz et al. 2024). Grid charges, particularly the power charge, dominate the levelised cost of heat and undermine competitiveness, even during surplus/ negative price periods. Consequently, much of the installed PtH capacity is not utilized in electricity markets.

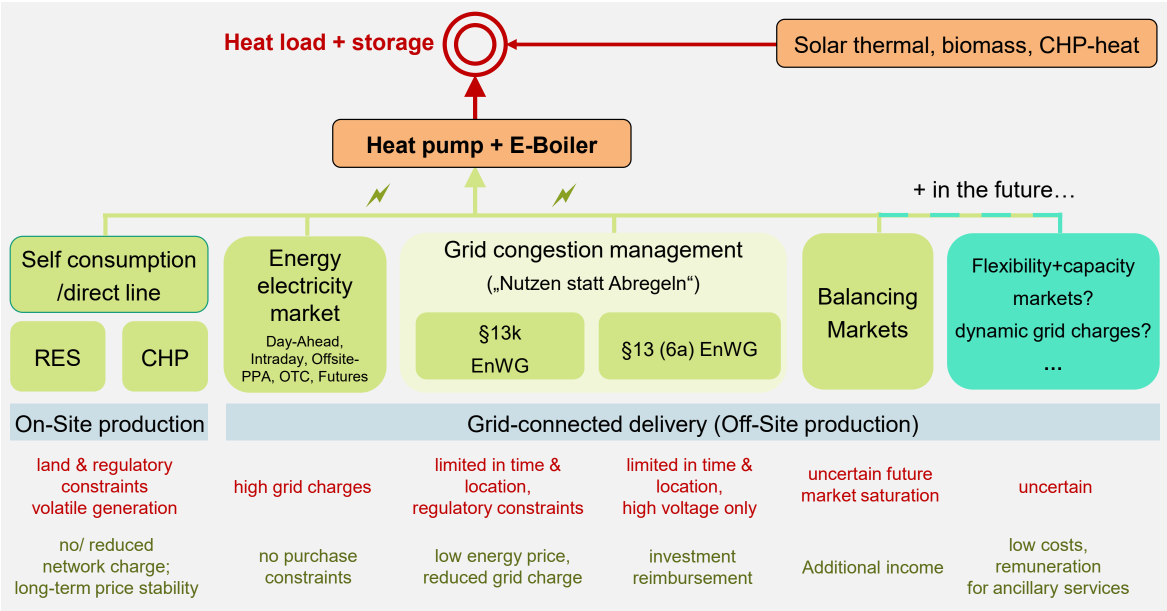

Fig. 1: Electricity procurement for Power-to-Heat; current options in Germany. Disadvantages/barriers are shown in red below, advantages in green below.

In Figure 1, relevant electricity procurement options for PtH plants under German regulation are depicted. On-site production represents a favourable option. Particularly from renewables, heat systems can strengthen generation-side flexibility without curtailment, though near-site potential is often limited by the urban location of district heating networks. To the right in Figure 1, all grid-based electricity sources are shown. The most common form of electricity procurement via energy markets enables price-guided operation of heat pumps and electric boilers; however, as noted above, procurement is not economical at low full-load hours despite negative prices. Very attractive options arise from grid-congestion-management procurement, but regulatory constraints exist to avoid cross-subsidy-driven distortions. The future of balancing markets remains uncertain.

To unlock the potential of flexibility for PtH systems in Germany, market designs that value long-duration flexibility are needed. This requires new instruments such as dynamic grid tariffs and flexibility or capacity remuneration, along with certainty of future revenue streams.

3. Flexibility potential of District Heating

With limited potential for shifting end-user heat demand, electrical demand-side flexibility can mainly realised through two approaches: (a) “fuel-switch” options enabled by a diversified plant portfolio (PtH, CHP, fuel-based boilers, biomass boilers and waste incineration); (b) use of large-scale thermal storages.

In both approaches, centralized district heating offers clear advantages over decentralized heating. For (a), decentralized building energy systems typically operate with mono- or bi-valent heat generation and limited oversizing for cost reasons, whereas district heating networks exploit scale effects to deploy a variety of heat sources and enable financially viable oversizing of the total capacity. For (b), district heating enables very large storage units impractical at the individual-building level. Larger storages reduce heat losses, improve performance (e.g., temperature stratification), and lower specific investment costs. A practical example is the district heating network in the German village of Bracht, which integrates a pit thermal energy storage of 26,600 m³ (Lang et al., 2024). This corresponds to about 140 m³ per connected building—roughly 8 MWh per building—a scale infeasible if each building carried its own storage.

Furthermore, both approaches enable short-term and long-duration flexibility of several hundred hours up to more than 1,000 hours of continuous operation — i.e., negative and positive flexibility far beyond the typical high-cyclic charge and discharge time spans of batteries (1–8 h).

The average summer heat load of German district heating networks is predominantly limited to domestic hot water demand. Consequently, especially during periods of high photovoltaic output, opportunities for (a) are constrained to around 5–6 GW_{th}.

Using approach (b) only with daily short-term summer storages (4 h charge, 20 h discharge) positive flexibility could be increased to 30-35 GW_{th} in the charge phase, which underscores the potential of heat storages.

In Figure 2, cumulative heat storage capacities in German district heating networks are shown, and a steady growth is evident. In comparison with electrical storage (while keeping in mind that the different forms of energy are only partially comparable), the capacity of battery storage is clearly smaller but is known to be growing strongly, while pumped hydro storage capacity remains nearly constant due to limited expansion potential. Among the thermal storage options, a wide variety of short- to long-duration storage types are present. With only two projects, the share of PTES (pit thermal energy storage) remains small, but a strong increase is expected.

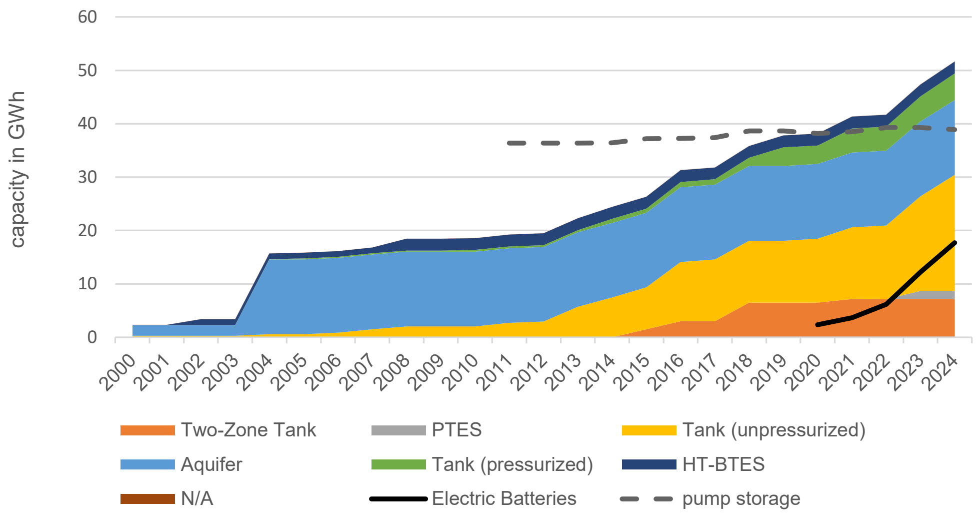

Fig. 2: Installed storage capacity in district heating sector in GWh_{th} & electricity sector in Germany in GWh_{el} (until 2025, desk research based on scientific literature and industry reports, regulatory documents, statistics). Abbreviations: PTES - pit-thermal energy storage; HT-BTES - high temperature borehole thermal energy storage.

The future potential of heat storages is significant. If all district heating systems were equipped with just daily heat storages sized for summer operation (esp. domestic hot water), they would collectively provide around 120 GWh of thermal capacity, more than twice the current installed thermal storage capacity in Germany and three times that of the electric storage capacity of pumped hydro storage plants. Twenty realizations of a PTES of 500,000 m^3, as currently discussed in some German district heating networks, would activate a cumulated capacity of about 600 GWh.

Advantages of heat storages extend beyond electric flexibility: they enable shifting large quantities of renewable energy, replacing high-temperature fuels - particularly fossil fuels - achieving very high shares of renewables in heating, improving CHP operation, and capturing surplus waste heat. This increases system flexibility and renewable integration, and enhances the security of supply for district heating operators and, in turn, the entire German energy system.

Given that costs for large storages range from about 5–20 €/kWh(cap) for short-term storages to 0.5–2 €/kWh(cap) for long-term storages—versus 200–350 €/kWh(cap) for large battery systems—they should play a significant role in the future energy system.

4. References

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