REGULATORY ASSISTANCE PROJECT

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# Flexing industrial muscle: Electrifying process heat with electro-thermal energy storage

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## Executive summary

**European industry is a very large user of heat,** consuming 1,900 TWh heat per year for processes[1,2] ranging from melting glass and steel or firing ceramics at high temperatures (800-1,500C) to generating hot water and steam (<200C) for chemical, food and drink processing. This is roughly equivalent to the amount of energy needed for space and water heating in 50% of all European buildings.[3]

**The electrification of heat is emerging as a main pathway for decarbonisation, industrial modernisation and competitiveness of European industry.**[4] It makes the most of an increasingly decarbonised electricity grid and will lead to high energy savings through increased energy efficiency, reducing the need for fossil fuel imports. Currently, only 3-4% of industrial process heat is generated using electricity. With current commercially available technology, however, 60% of this heat could be electrified.[5]

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[1] The authors would like to thank Daniel Gallis (World Business Council for Sustainable Development) and Andreas Jahn, Monika Morawiecka and Zsuzsanna Pató (Regulatory Assistance Project) for their helpful comments and insights on earlier drafts of this paper.

[2] Based on final energy demand. Fraunhofer ISI. (2024). *Direct Electrification of Industrial Process Heat: An Assessment of Technologies, Potentials and Future Prospects for the EU.* https://www.agora-industry.org/fileadmin/Projects/2023/2023-20_IND_Electrification_Industrial_Heat/A-IND_329_04_Electrification_Industrial_Heat_WEB.pdf

[3] Based on 3445 TWh final energy use. European Commission: Directorate-General for Energy. (2022). Renewable space heating under the revised Renewable Energy Directive: ENER/C1/2018 494 : Final Report. Publications Office of the European Union. https://data.europa.eu/doi/10.2833/525486

[4] Rosenow, J., Oxenaar, S. & Pusceddu, E. (2024). *Some like it hot: Moving industrial electrification from potential to practice.* https://www.raponline.org/knowledge-center/some-like-it-hot-moving-industrial-electrification-from-potential-to-practice/

[5] Fraunhofer ISI, 2024.

Several barriers hinder the broad uptake of electrification solutions for process heat, especially the **high price of electricity compared to fossil fuels and insufficient electricity infrastructure**. In addition, many industrial heat users are unaware of the wide range of electrification solutions now commercially available.

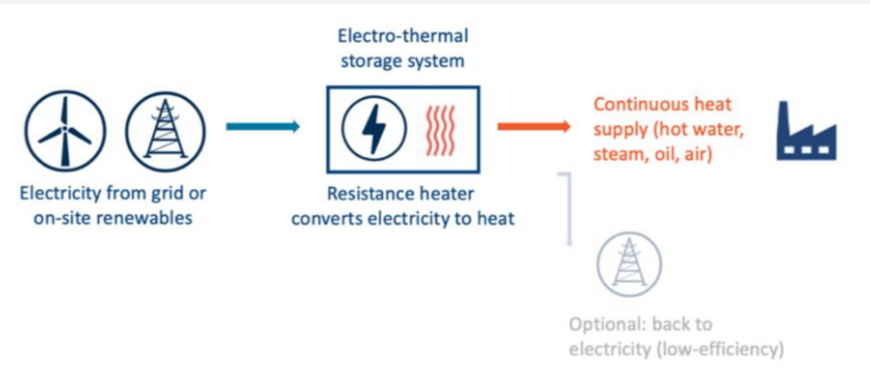
Electrifying industrial heat is not only key for decarbonisation, modernisation and competitiveness **but can enable significant potential for demand-side flexibility in the electricity system, which is essential to achieve cost-effective integration of renewable energy. As industrial** processes often require a continuous supply of heat, electrification should be combined with storage to be able to shift electricity demand in time (demand response).

**Wide-scale deployment of electro-thermal energy storage (ETES) could bring both public and private benefits, including cost savings for industry** through, potentially, reduced average costs of electricity due to flexible offtake; additional revenue from participation in ancillary and flexibility services; and (cheaper) flexible connections to the grid. Moreover, when combined with local renewable energy sources, ETES can enhance the resilience of an industrial facility to energy supply and price shocks. Increased flexibility from industrial demand can lead to **lower system costs for all** due to reduced renewables curtailment, potentially lower grid upgrade needs and reduced system management costs.[6]

## What is electro-thermal energy storage?

ETES technologies, sometimes called heat batteries, use electricity to generate and store heat (see Figure 1). Heat is generated, often using a resistance heater, and stored in low-cost media such as rocks, bricks, low-grade metal, sand and/or salts. The main application of ETES is to turn variable renewable or off-peak electricity into heat, store it, and release it on demand for process heating, typically steam, thermal oil, hot water or air. When taking electricity from the grid (charging) these technologies can make use of the lowest price hours and avoid times with peak prices, reducing the average cost of electricity for the end user.

**Figure 1. Use of electro-thermal storage in industry (schematic overview)**




[6] Stefanussen Foslie, S., Rugstad Knudsen, B., Bjarghov, S., & Korpås, M. (2024). Faster Decarbonization of Heavy Industries in Low-Carbon Power Grids: Using Process Flexibility for Handling Grid Congestions. *Energy & Environmental Science*. https://doi.org/10.1039/D4EE03888F

# Why do we need electro-thermal energy storage?

ETES has the potential to be a key solution for industrial electrification, as it can enable more flexible electricity demand without interrupting heat delivery.

As industrial heat generation electrifies over the coming decade, its potential to provide demand-side flexibility (DSF) will increase significantly (see text box on next page). There are two ways in which industrial demand for electricity can be shifted. The first is direct demand-side flexibility, where temporarily lowering (or increasing) heat demand leads to lower (or higher) electricity demand, for example, by scheduling processes to run at specific times of the day or week or running equipment at lower or higher capacity (modulation). The second requires the integration of either electric or thermal storage into the process, allowing continuous heat demand but reducing electricity off-take from the grid when beneficial.

Direct demand-side flexibility using scheduling or modulation has long been used in industry to benefit from off-peak electricity prices, especially in electricity-intensive industries that operate non-continuous ('batch') processes such as electric arc furnaces for steel recycling.[7] This method, however, is not viable for processes with continuous or hard-to-schedule heat demand. It also provides limited economic benefits for industries that are not very sensitive to the cost of electricity, given the added complexity and cost of flexible operations.

The second option, however, could be applied widely across industrial sectors using electricity storage (lithium-ion, or Li-ion, batteries) combined with heat electrification equipment such as a heat pump or e-boiler. ETES, however, could be more beneficial as it generally has lower total installed costs compared to electricity storage with an electrified heating solution, as it uses low-cost materials for the storage medium,[8] can achieve higher longevity and possibly higher energy density,[9] and generally has higher energy efficiency when delivering heat (and not electricity) than batteries.

Until recently, thermal energy storage largely took the form of hot water tank storage and was meant for lower temperature applications such as domestic hot water and space heating or very short-term storage (buffering) in industry. But, as hot water storage offers limited energy density and a low maximum temperature, additional thermal energy storage options are needed for industrial uses.[10]

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[7] Boldrini, A., Koolen, D., Crijns-Graus, W., Worrell, E., & van den Broek, M. (2024, January). *Flexibility options in a decarbonising iron and steel industry*. Renewable and Sustainable Energy Reviews Volume 189 Part B. https://doi.org/10.1016/j.rser.2023.113988

[8] SYSTEMIQ. (2024). *Catalysing the Global Opportunity for Electrothermal Energy Storage*. https://www.systemiq.earth/wp-content/uploads/2024/03/Global-ETES-Opportunity-Report-240227.pdf

[9] Singhvi, S. & Gallis, D. (2025). *Renewable Industrial Heat Navigator Brief: Thermal Energy Storage*. WBCSD. https://www.wbcsd.org/wp-content/uploads/2025/02/Renewable-industrial-heat-navigator-brief_Thermal-energy-storage.pdf

[10] Joint Research Centre. (2023). Clean Energy Technology Observatory, Novel Thermal Energy Storage in the European Union: Status Report on Technology Development, Trends, Value Chains and Markets : 2023. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/394103

ETES is changing this with increasing deployment of systems delivering heat in the range of 200-300C,[11] and systems capable of delivering up to 400C commercially available.[12] Beyond being able to store energy as heat for hours to days, these ETES systems can generate high temperature heat at the scale and temperature needed for many industrial processes. The current generation of ETES systems is especially applicable for steam or hot water provision in light industry, as it can be integrated easily into common processes across the food and drink, paper and pulp, and textiles industries. But it is also relevant for heavy industries such as chemicals and alumina refining, which are among the largest steam users. In the lower temperature ranges (<160C) ETES, however, also competes with more efficient - but less flexible and not always applicable - industrial heat pumps.[13]

# The potential for industrial demand-side flexibility with electro-thermal energy storage

The technical potential for ETES to provide demand-side flexibility is significant. Meeting just 10% of industrial heat demand with thermal storage would amount to 80GW of demand-side flexibility potential - around 2.5 times the total installed electricity storage capacity in Europe in 2024 (35 GW).[14] Actual technological potential for industrial demand response is likely much higher. One study indicated that 20-30% of process heat generation globally could become flexible in 2050, based on the current outlook, with even greater potential in a high adoption of electric and thermal storage scenario.[15]

Moreover, without deployment of storage the flexibility potential of electrified heat will be much more limited, as industry would like to run their processes for as many hours per year as possible. For example, looking at industrial demand-side response potential without electrified heat, one study found a potential of around only 22GW by 2030.[16]

[11] Singhvi & Gallis, 2025.

[12] SYSTEMIQ, 2024.

[13] SYSTEMIQ, 2024.

[14] LCP Delta and EASE. (2025). *European Market Monitor on Energy Storage 9.0 (EMMES)*. https://ease-storage.eu/publication/emmes-9-0-march-2025/

[15] Energy Transitions Commission. (2025, January). *Demand Side Flexibility - Unleashing Untapped Potential for Clean Power*. https://www.energy-transitions.org/wp-content/uploads/2025/02/DSF-Briefing-Note_DigitalFinal.pdf

[16] smartEn & DNV. (2022). *Demand-side flexibility: Qualification of benefits in the EU*. https://www.dnv.com/publications/demand-side-flexibility-quantification-of-benefits-in-the-eu-232342/

### Why our electricity grid needs more flexibility

Our electricity grid is in increasing need of being able to **respond to variability in supply** (and demand). Variation occurs across different timescales, from seconds - such as a clouds limiting solar PV output - to months, as with seasonal shifts in sun and wind generation and also in electricity demand. **Flexibility can be supplied by any element of the electricity system that can controllably and dynamically increase and/or reduce its supply and/or demand of electricity.** Flexibility can stem from, for example, a power plant, a storage system, or users modifying their demand.

Across the EU, the hourly to weekly flexibility needs on the grid are expected to increase multifold.[17] In addition to expanding the number of interconnectors between countries and ramping up electricity storage, demand-side flexibility has a key role to play.[18]

More flexibility will help achieve:

- **24/7 clean electricity and allow continuous growth of renewables** as demand can better adapt to the availability of renewable generation.
- **Lower electricity prices and reduced-price volatility** by reducing peak demand and less use of expensive gas plants generating at peak times.
- **Reduce renewable curtailment, grid congestion and related costs** when flexibility is available at the right location and time to improve matching of supply and demand.

# Making the economics of electro-thermal energy storage work

There are many benefits to electrifying heat and enabling more demand-side flexibility, including cost savings for industry, yet it is currently difficult to make the business case for the combination of ETES and electricity from the grid. Electrification of heat can deliver savings on fuel and emission allowance costs and generate revenue for industrial end-users through provision of electricity system services. Generally, however, this does not yet outweigh the (much) higher cost of electricity compared to that of fossil fuels across Europe. Especially as, per unit of energy, electricity is often taxed much higher than gas or oil and has more levies applied to it.[19]

Combined with the relatively high initial cost of financing new equipment, elevated electricity prices lead to overly long investment payback times. While technologies utilising lower

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[17] Koolen, D., De Felice, M., & Busch, S. (2023). *Flexibility Requirements and the Role of Storage in Future European Power Systems*. Publications Office of the European Union. https://doi.org/10.2760/384443

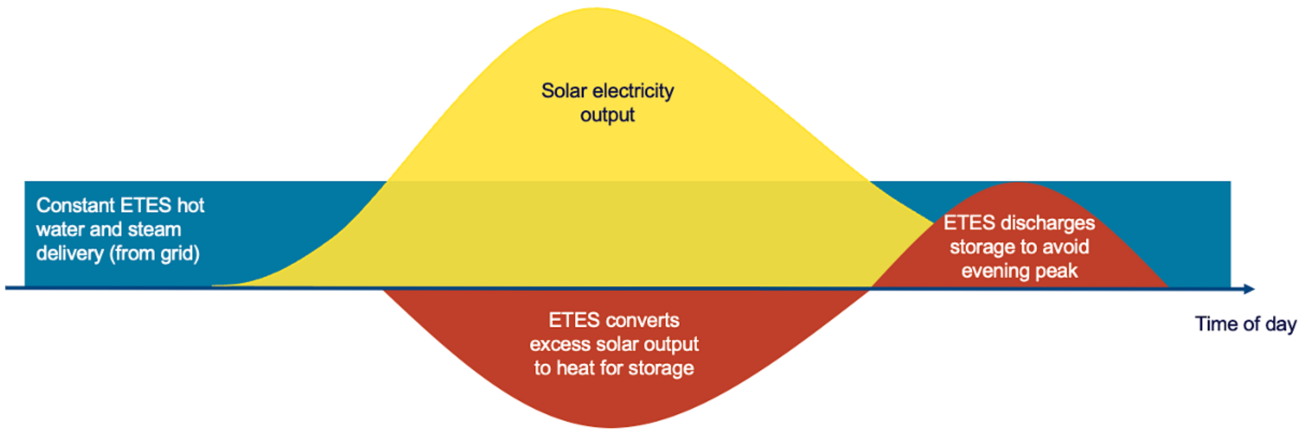
[18] Yule-Bennett, S. & Sunderland, L. (2022, June). *The Joy of Flex: Embracing Household Demand-Side Flexibility as a Power System Resource for Europe*. Regulatory Assistance Project. https://www.raponline.org/wp-content/uploads/2022/06/rap-yule-bennett-sunderland-joy-flex-household-demand-side-flexibility-2022-june-new.pdf

[19] Rosenow, Oxenaar, & Pusceddu, 2024.

temperature heat, such as industrial heat pumps, are already more cost efficient than fossil fuel boilers in many European countries due to their very high efficiency, this is not yet the case for higher temperature solutions which require more electricity and at higher capacities, such as ETES.[20]

Industrial firms can lower their cost of electricity by installing onsite renewables such as solar PV and wind turbines in conjunction with storage. In this case, ETES is charged at times of high onsite production, as made visible by the schematic in Figure 2. In the case of solar PV, for example, peak charging is around noon on a sunny day, with the heat stored for later use (see Figure 3). Additional electricity is taken from the grid when onsite production is not sufficient. The average cost of electricity is reduced due to the low cost of electricity generated onsite, savings on grid tariffs and the ability to evade peak prices; combined, these returns outweigh the cost of investment in onsite generation. Not every industrial site, however, has the space available for (enough) onsite renewable energy generation.

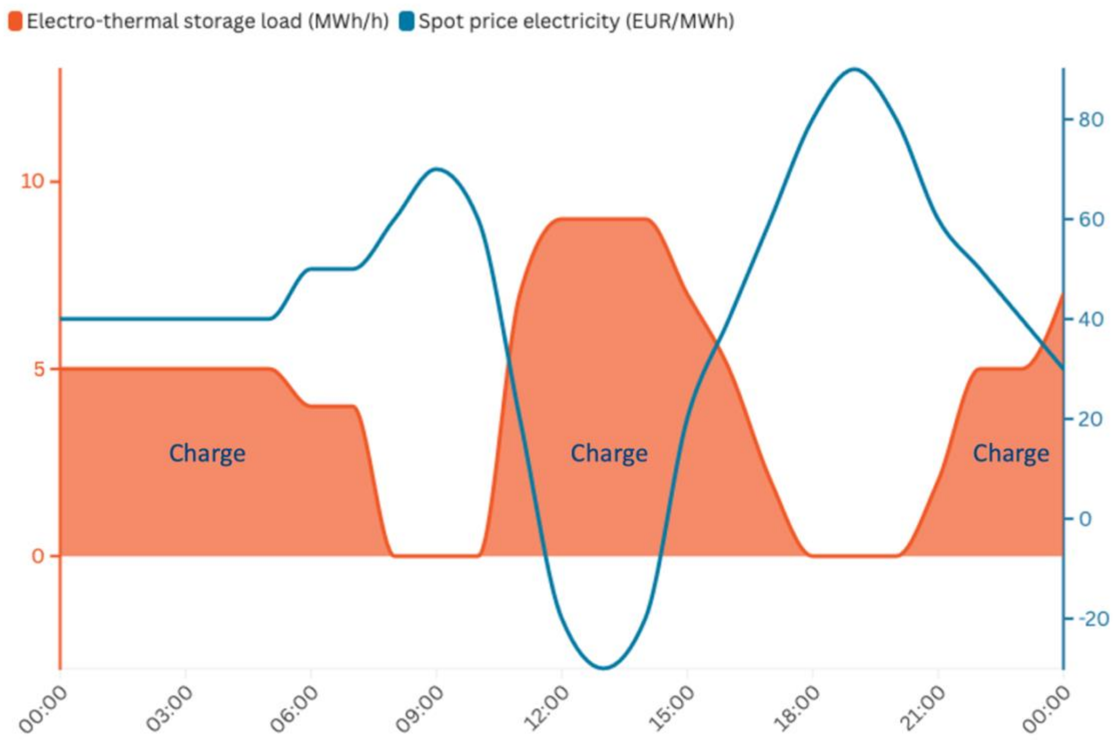
**Figure 2. Charging ETES with electricity from onsite solar and the grid (schematic overview)**




Lower electricity costs can also be achieved by optimizing charging profile when using electricity from the grid. Electricity prices can vary widely throughout the day (see textbox on flexibility). And charging costs can be reduced by buying electricity from the grid when prices are low, or even negative, and reducing electricity demand when prices are high, drawing from the storage instead to meet heat demand (Figure 4). Although it is technologically feasible to store heat for several days, to become economically viable, ETES systems will likely need to run several cycles a day and can realistically shift demand by around 4-8 hours.

[20] SYSTEMIQ, 2024.

**Figure 3. Charging ETES only with electricity from the grid (schematic overview)**




Although flexible use of ETES means drawing more electricity from the grid in fewer hours, necessitating a larger grid connection compared to constant use, flexible connection agreements (‘non-firm contracts’) could potentially alleviate this constraint. With flexible connection agreements, end users do not have continuous access to the grid and/or at the same capacity levels, although flexible connection agreements could be combined with shared connections on industrial sites to facilitate quicker grid access. In this way, an end user with spare grid capacity at specific times could, for example, lease or share this space with other onsite end users.[21] Another viable compromise that still delivers significant fossil fuel and emissions savings would be a hybrid system, where the ETES is installed in addition to an existing fossil fuel heat generation technology (see textbox).

Finally, flexible use of ETES could generate additional revenue for end users from the provision of system services such as balancing, ancillary, and local network flexibility, and/or participation in capacity mechanisms. Most very large industrial electricity users already participate in such schemes, but ETES could enable a wider range of industrial end users to utilize these options, especially through aggregators and heat-as-a-service.

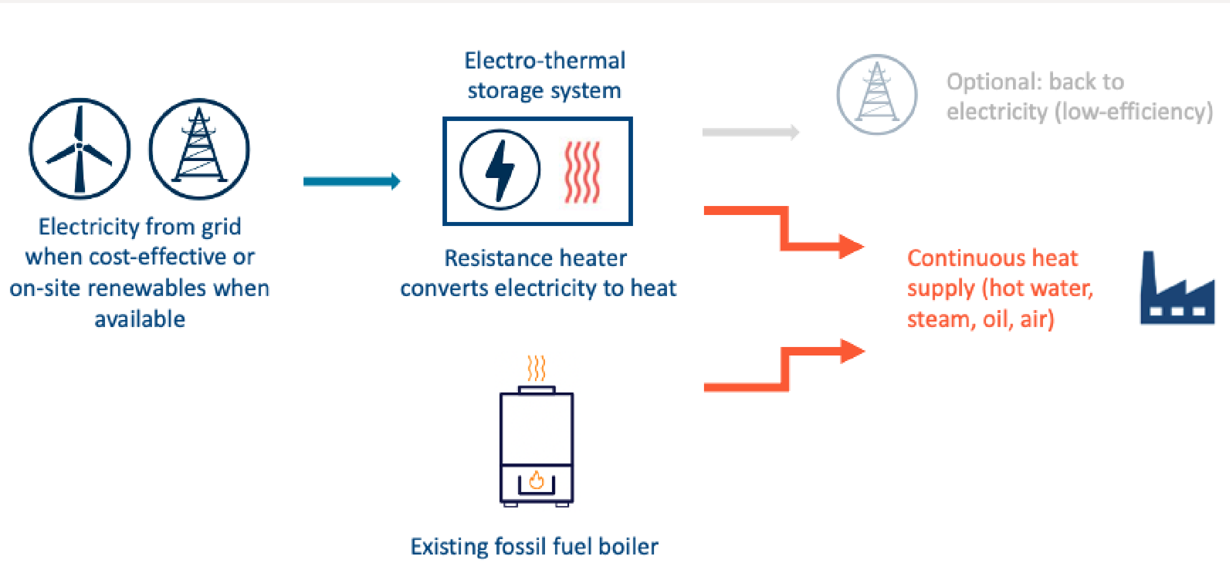
[21] Pató, Z. (2024). *RIP First Come, First Served*. Regulatory Assistance Project. https://www.raponline.org/toolkit/rip-first-come-first-served/

### Why going hybrid gas-electric with ETES makes sense

ETES offers the potential to electrify industrial heating at comparable or lower cost than fossil fuels, as low-cost electricity is available at least part of the day. Even though low or negatively priced electricity is becoming increasingly common in regions with high solar and/or wind generation, however, wholesale prices can remain high for extended periods – even up to a couple of weeks. During these times there are limited to no possibilities for low-cost grid charging, with detrimental effect for the business case of all-electric ETES systems.

This makes adding an ETES to existing fossil heaters on site a sensible compromise. Hybrid projects allow site operators to decide which heating system to use depending on market prices (see Figure 4). Plenty of sunshine or strong winds and near-zero electricity prices? Charge the ETES at full power. Gas peaking plants are called in to balance the grid and electricity prices go up? Use the gas boiler and avoid price spikes. This brings not only financial benefits, but could also lower emissions at system level, especially in countries with high fossil fuel use in the electricity mix.

**Figure 4. Hybrid ETES use (schematic overview)**




# Policy recommendations for electro-thermal energy storage

Promoting the installation of ETES and uptake of demand-side flexibility in industrial heat requires a mix of policies tackling the economic, regulatory and infrastructure barriers. In doing so, it is important to safeguard total system efficiency to ensure lowest costs for all end users. This requires addressing four key areas:

## Prioritise electrification of industrial heat.

- Put in place targeted programmes to increase the electrification rate in industrial heat, tackling economic, infrastructure, technological and awareness barriers.[22]
- Ensure fair access to public support for all electrification technologies, including electro-thermal storage, in EU State aid and national government programmes. Consider setting up dedicated policies for demand-side flexibility in industry.

## Reduce the price of electricity compared to fossil fuels.

- Rebalance taxes and levies between electricity and gas to reduce the price ratio between electricity and gas. Additionally, a tax discount could be considered for electricity used for heat when paired with energy efficiency measures.[23]

## Incentivize flexible use of electricity.

- Reform network tariffs[24] and electricity prices[25] to be time-differentiated (time-of-use) and possibly even locational. This incentivizes flexible use while ensuring demand-side flexibility is provided at the times when and locations where it is most beneficial to the system.

## Connect flexible loads to the grid.

- Allow flexible connection agreements and consider offering discounted tariffs in line with the benefit provided by such contracts. For example, grid operators could provide a discount to end users that allow their connection capacity to be temporarily reduced at pre-determined times or with sufficient notice.[26]
- Ensure easy market access for demand-side flexibility, including for smaller end users and through aggregators.[27]

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[22] Rosenow, Oxenaar, & Pusceddu, 2024.

[23] Rosenow, J., Thomas, S., Gibb, D., Baetens, R., De Brouwer, A., & Cornillie, J. (2022). Levelling the playing field: Aligning heating energy taxes and levies in Europe with climate goals. https://www.raponline.org/knowledge-center/aligning-heating-energy-taxes-levies-europe-climate-goals/

[24] Claeys, B., Hogan, M., Jahn, A., Morawiecka, M., Pató, Z., D., T., & Yule-Bennett, S. *Smart Network Tariffs – RAP Blueprint.* https://blueprint.raponline.org/smart-network-tariffs/

[25] Claeys, B., Hogan, M., Jahn, A., Morawiecka, M., Pató, Z., D., T., & Yule-Bennett, S. *Locational Marginal Pricing – RAP Blueprint.* https://blueprint.raponline.org/locational-marginal-pricing/

[26] Pató, 2024.

[27] Claeys, B., Hogan, M., Jahn, A., Morawiecka, M., Pató, Z., D., T., & Yule-Bennett, S. *Market Access for Demand-Side Flexibility – RAP Blueprint.* https://blueprint.raponline.org/market-access-for-demand-side-flexibility/

# Annex: Policy examples

Across Europe, countries are already putting in place the policies needed to drive ETES and demand-side flexibility from industrial heat. Table 1 provides an overview of selected policy examples.

**Table 1. Policies driving industrial electrification and demand-side flexibility**

| Prioritise electrification | Reduce price ratio | Incentivise flexible use | Connect flexible loads |
|---|---|---|---|
| Finland: Electrification of industry and affordable electricity is a political priority **and** financially supported**.** | Denmark and Finland: Tax reduction for industrial electricity users (for heat). | Denmark: Geographically differentiated connection charge and network tariff for producers at the transmission grid. | Denmark: flexible connection agreement for users on transmission system allowed. |
| The Netherlands: Targeted subsidy for mid-size electricity users to enhance their demand response potential. | The United Kingdom: announced levy reduction on electricity for selected firms/sectors. | Germany: Reforming grid tariff for industrial users to incentivize flexible electricity use. | The Netherlands: flexible connection agreements, capacity limitation contracts, and cable pooling allowed. |
| Spain: Investment subsidy for (thermal) storage. | Germany: shifted its renewable energy levy from electricity bills into general budget | The Netherlands: Time-of-use tariffs and discounts for flexible demand under consideration | United Kingdom: Demand Flexibility Service enabling easy access to electricity markets. |

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