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Flex Machina: Unlocking industrial flexibility's full potential

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Summary

The electrification of heat is a key modernisation pathway that enables industry to make the most of an increasing supply of home-grown renewable electricity and reduce dependence on imported gas.[1] However, the high price of electricity compared with fossil fuels is holding back wider adoption of clean heat technologies such as heat pumps, electric boilers, and electro-thermal energy storage. While governments and regulators act to structurally reduce electricity prices,[2] industry has an opportunity to be innovative with its heating processes, using flexible operational strategies to improve the near-term business case for electrification. This briefing takes stock of this potential, and introduces recommendations on how best to capitalise on it.

This briefing[3] describes how common light-industrial processes in sectors such as food and drink, paper and pulp, textiles, and chemicals, can implement flexible electrification to displace gas-fired process heating. It shows that, for many European countries, a viable business model for industrial flexibility requires value to be stacked, with industry taking advantage of periods with low electricity prices while also providing system services to earn

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

[2] Sunderland, L., Pató, Z., Morawiecka, M., & Claeys, B. (2025). *Making electricity cheaper: RAP's eight priority actions*. Regulatory Assistance Project. https://www.raponline.org/wp-content/uploads/2025/09/rap-sunderland-pato-morawiecka-claeys-eight-priority-actions-september-2025.pdf

[3] The authors would like to acknowledge and express their appreciation to the following people who provided helpful insights into early drafts: Marco Giuli (Agora Industry), Elian Pusceddu (Independent Consultant), and Louise Sunderland, Zsuzsanna Pató, Marion Santini and Andreas Jahn from the Regulatory Assistance Project.

extra revenue. Our case study demonstrates that this is the case in Germany, where the price of electricity does not currently drop below the price of gas frequently enough to make investments in flexible electrified heating equipment attractive without drawing on other value streams (e.g., from flexibility system services). In a small number of European countries, electricity prices already drop below the price of gas frequently enough that they can rely less on revenue from other value streams. Our case study shows that this is the case in Spain, where flexible heating technology is close to being cost competitive even without the additional revenue from system service provision.

This briefing also provides recommendations for decision makers on how to promote industrial flexibility:

- Regulators should encourage suppliers to offer tariffs that pass through low wholesale costs to consumers.
- Regulators should encourage system operators to introduce time-of-use network tariffs that help flexible demand (such as industry) to access lower electricity prices during times when the grid infrastructure has plenty of capacity, rather than penalising it with indiscriminate capacity charges.
- Regulators should ensure that rules for entry into system service markets enable access to industrial assets and their aggregators.

These policy recommendations can be enacted in parallel with a wider suite of reforms aimed at making electricity cheaper and unlocking electrification, to underpin European energy security.[4]

Introduction

The electrification of industrial heat with home-grown renewable energy has emerged as the leading strategy to guarantee the energy security of European industry, while tackling the sector's significant greenhouse gas emissions. Technologies that are commercially available today can electrify as much as 60% of Europe's industrial process heat, and – assuming technology develops as expected – this is likely rise to approximately 90% by 2035.[5]

Despite the high potential, growth in industrial electrification is slow and only 4% of Europe's industrial process heat is currently electrified.[6]

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[4] See recommendations in Rosenow, Oxenaar and Pusceddu, 2024; Sunderland, Pató, Morawiecka and Claeys, 2025

[5] Rehfeldt, M., Bussmann, S., & Fleiter, T. (2024). *Direct electrification of industrial process heat: An assessment of technologies, potentials and future prospects for the EU*. Fraunhofer ISI. https://www.agora-industry.org/publications/direct-electrification-of-industrial-process-heat

[6] Olikathodi, A. A. (2024). *Power Barometer 2024: Zeroing in on industrial electrification, energy security and decarbonisation*. Eurelectric. https://powerbarometer.eurelectric.org/wp-content/uploads/2024/10/Power-Barometer-2024_Full_report.pdf

There are two major barriers to progress in industry's switch from gas to electricity: the high average electricity-to-gas price ratios prevalent across many European countries, and the long lead times for industrial connections to the electricity grid.

While long-term system-wide reforms are being developed to address these barriers on a structural level, there is also a pressing need to create innovative solutions to help mitigate them in the near term. Industrial flexibility presents an opportunity for sites to access lower average electricity prices, helping to mitigate high price ratios. This briefing describes how electrified industrial processes can be flexible, how different flexibility value streams can improve the business case for electrification, and what policy and regulatory changes are needed to ensure that this can take place. The potential of flexible heat electrification is explored in the instances of Spain and Germany in our case study at the end of this brief. Flexible industrial demand may also help to mitigate long lead times for grid connections, but the subject is not explored in this paper.

How light industry can deploy flexible electrified heat

Around 40% of European industrial heating occurs at temperatures below 200 °C and is often delivered in the form of hot water, steam, heating oil, or heated air.[7]

Industrial-size heat pumps can provide heat at temperatures up to about 160 °C, and their high efficiency makes them very attractive for processes with large consistent heating requirements. Certain types of heat pumps have the technical potential to be operated flexibly; however, as a capital-intensive technology, industrial heat pumps generally favour applications where they are run continuously, to spread capital costs over a large number of operating hours.

E-boilers and electro-thermal energy storage (ETES) systems can generate heat at higher temperatures than heat pumps and excel in flexible operations.[8] These technologies often have lower upfront costs relative to heat pumps and may not need to be utilised quite as highly in order to pay back the associated initial investment. This is attractive for flexible heating which may involve periods where equipment is operated at low utilisation rates.

In practice, a site may have a range of industrial processes with varying technological needs, which means that a combination of electrification technologies may be necessary – e.g., a heat pump for a site's baseload heat demand and an e-boiler or ETES for processes with flexible, peaking heat demand. Many common processes in light industrial sectors such as food and drink, textiles, paper and pulp, manufacturing, and chemicals can be electrified in this way.[9] To deploy electric heat flexibly, industrial players can put in place one or more of the following strategies.

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[7] de Boer, R. et al. (2020). *Strengthening industrial heat pump innovation: Decarbonizing industrial heat.* SINTEF Energi AS & TNO & AIT. https://www.sintef.no/globalassets/sintef-energi/industrial-heat-pump-whitepaper/2020-07-10-whitepaper-ihp-a4.pdf

[8] Rehfeldt, M., Bussmann, S. Fleiter, T., 2024

[9] Madeddu et al. (2020). The CO_2 reduction potential for the European industry via direct electrification of heat supply (Supplementary Material). *Environmental Research Letters*, 15(12): 124004. https://doi.org/10.1088/1748-9326/abbd02

Electrify and adjust the heat demand profile

An industrial site that plans to adopt flexible electrified heating should first consider whether its incumbent heat demand profile has the potential to be adapted. Traditionally, industrial processes which use fossil fuels for heat have been scheduled based on operational considerations such as convenience, integration with other production processes, and the availability and cost of labour. Within light industrial sectors many sites may appear to be running continuous processes, when in fact they are running multiple similar processes with staggered start times.

There are two main approaches for adjusting the heat demand profile of an industrial site, and these can be combined. First, non-continuous processes can often be deferred to a different period of the day (*shift*). Second, the amplitude of the heat demand profile and the time window of processes can be adapted (*shape*).

Shifting and shaping industrial heat demand

Shifting: Non-continuous processes can often be deferred – shifted – to a different period of the day, without having much impact on site-level production. The nature of each individual process remains unchanged. This principle is already commonly applied in many electro-intensive industries that shift their batch production to periods when electricity is cheaper. Batch industrial processes present particularly good opportunities for industrial flexibility, since their heat demand is non-constant and may be deferable.[10] Common examples of batch processes within Europe's light industrial sectors include fermentation and cooking in the food and drink sector, dyeing and washing in the textiles sector, active ingredient synthesis in the pharmaceutical sector, the formation of specialty chemicals (resins and polymers), and surface treatment and painting in the automotive sector.

Shaping: 'Shaping' demand refers to adapting the amplitude of the heat demand profile, as well as the time window of the process. This is different to simply 'shifting' demand which involves a change in the scheduling of a process but not in its heating profile. Demand may be shaped over short timeframes by temporarily increasing or decreasing thermal load, e.g., in response to market signals for frequency response or capacity. Alternatively, the heating profile may be adapted on a more permanent basis, e.g., by increasing the standard production intensity and shortening the time-window of the process.

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[10] Shifting may also be used to manage peak power demand, by staggering coincidental processes instead of scheduling them to coincide. This helps to manage the capacity-dependent component of the grid tariff and enables sites to operate within the capacity limits of a physical connection and/or connection agreement.

Install electric technologies to form hybrid heating systems

Hybridisation refers to the practice of introducing electric heating technologies in parallel with pre-existing fossil fuel heating systems. A site's heating duty can be shared between electricity and fossil fuels depending on which provides the lowest-cost heat at a given point. Sites with hybridised electric heating systems have a high degree of flexibility due to their ability to switch between heat sources, reducing or increasing electricity consumption when required.

It is common for light industrial sectors such as food and drink, paper and pulp, textiles, chemicals, to provide heat to their processes in the form of steam. Often these sites will have a centralised boiler fired by fossil fuels which generates steam and distributes it to various processes across the site via pipes. These systems are often technically well suited to hybridisation, and electrified technologies such as an e-boiler or ETES can directly connect to the steam distribution systems and supplement the incumbent boiler's steam generation, often without causing much disruption.

While this does not fully displace fossil fuel use, hybridisation can provide a stepping-stone to full electrification and enables some constrained sites to electrify a portion of their heat in the interim. To avoid locking in reliance on gas, a hybridised heating system must be free to pivot away from gas to full electrification as soon as economics or grid constraints allow. In the example described above where flexible electric heating technologies are integrated into a steam distribution system, the pre-existing gas-fired assets become increasingly redundant as electricity gets cheaper and the share of cost-competitive electrified heating increases.

Thinking ahead

Sites that are currently constrained from installing heat pumps but eventually intend to use them as their primary source of heating can optimise the design of their interim hybrid heating systems so that the flexible heating technologies continue to provide value in future configurations.

Since heat pumps are often sized to meet a constant level of heat demand (rather than sizing for the site's peak heat demand), flexible electrified technologies that can provide supplementary heating are often complementary.

Install thermal energy storage

The introduction of an energy storage medium provides an opportunity to decouple a process's heat demand from grid electricity prices and thus extends the range of hours when electric heating can economically displace fossil fuel-based heating. Thermal storage technologies are of particular interest to industry, given that heat is often a cheaper form of energy to store than electricity and it is also the form of energy that industrial processes require. ETES is a technology that uses electricity to produce heat which can subsequently be stored using materials that retain heat well.[11]

During periods with low electricity prices, ETES systems can produce heat and store it. During periods where electricity prices rise above gas prices, it would typically become cheaper to heat with gas than electricity; however, ETES provides a third option – to liberate stored heat that was previously generated with cheap electricity. Consequently, ETES can increase the number of hours where gas is displaced by a cheaper form of heating.

Illustrating the flexible dispatch of electrified heating

Figures 1a, 1b, 1c and 1d illustrate how an industrial site with a gas-fired boiler could flexibly dispatch electrified heating equipment to take advantage of low-priced electricity.

Figure 1a depicts gas and electricity prices over a 24-hour period in Spain. During the early morning and in the middle of the day, electricity prices drop below the price of gas.

Figure 1a. Industrial electricity and gas retail prices

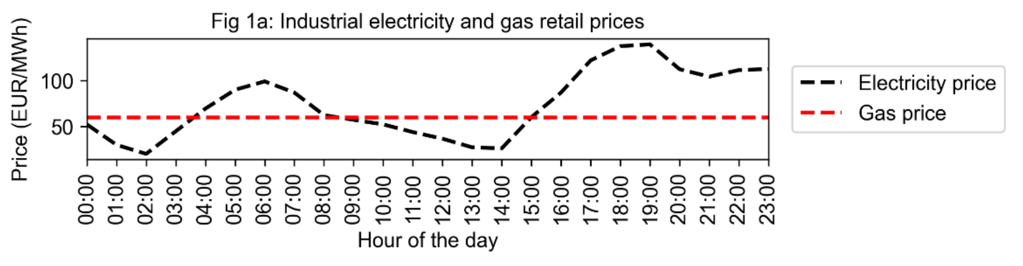
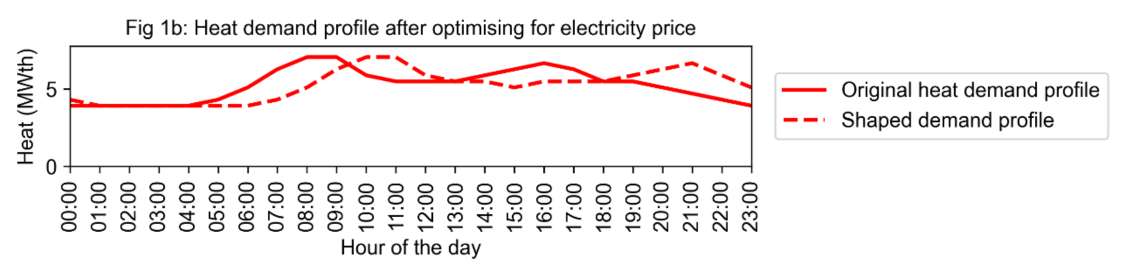


Figure 1b presents an illustrative heat demand profile of a site in a light industrial facility, e.g., a food and drink manufacturer. A centralised gas boiler is assumed to produce steam and hot water to meet the site's entire heat demand. Figure 1b also shows what an adapted version of the heat demand profile might look like. In this example, the morning demand peak is shifted to coincide with a period of negative pricing ('shift') while the demand peak in the early evening is flattened and shifted to the late evening ('shape'), reducing exposure to a period with high electricity prices.

Figure 1b. Heat demand profile after optimising for electricity price



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[11] Oxenaar, S. & Pusceddu, E. (2025). *Flexing industrial muscle: electrifying process heat with electro-thermal energy storage.* Regulatory Assistance Project. https://www.raponline.org/wp-content/uploads/2025/06/RAP-Oxenaar-Flexing-industrial-muscle-electrifying-process-heat-June-2025.pdf

Figure 1c shows what might happen if an e-boiler was introduced into the site as part of a hybridised heating system. During periods when electricity prices are cheaper than gas, the e-boiler is dispatched to meet the site's heat demand and the gas boiler is able to idle.

Figure 1c. Dispatch profile of hybridised gas boiler and e-boiler

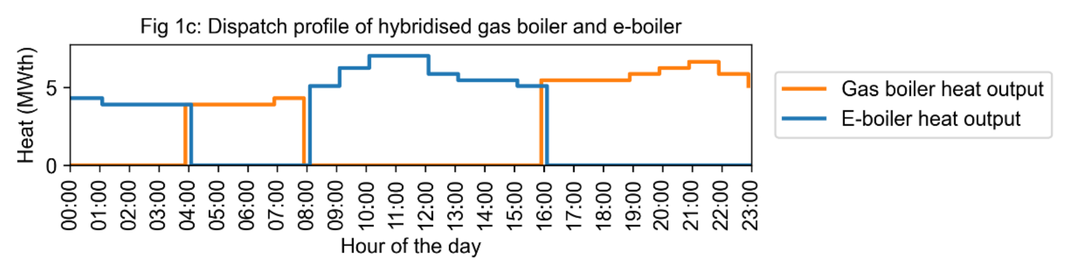
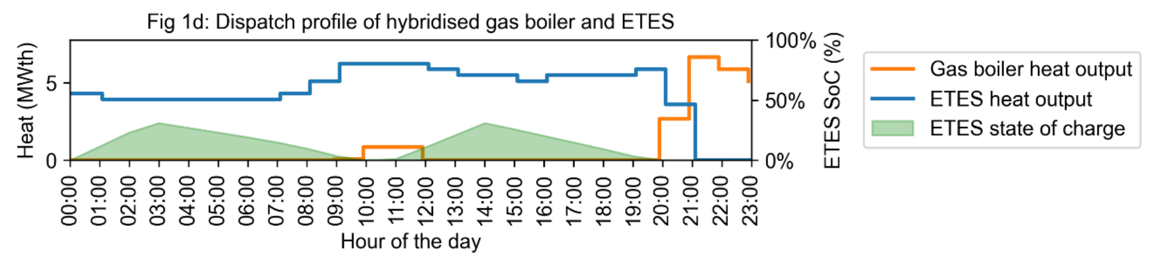


Figure 1d demonstrates how ETES might be operated at the site as part of a hybridized heating system. Our modelling is designed to only dispatch the ETES in a manner that minimises operating costs. During periods when electricity is cheaper than gas, the ETES generates hot water/steam directly from electricity while simultaneously charging up its thermal store. During hours when electricity is more expensive than gas, the ETES starts to discharge its thermal store. During this 24-hour period, ETES almost completely displaces the site's gas boiler.

Figure 1d. Dispatch profile of hybridised gas boiler and ETES



Creating value through flexibility

For industry to invest in electric technologies that deliver flexible heat, there must first be a viable business case to do so. Dispatching electric heating during periods when it is cheaper than the fossil fuel incumbent is an example of a flexibility value stream. Variations in electricity prices are driven by fluctuations in wholesale electricity costs and network tariffs, while overall costs are also impacted by the connection agreement of the industrial site. System operators can also directly procure flexibility through system service markets.

Access to low wholesale electricity price periods

Many European countries are experiencing increased occurrences of low, and even negative, wholesale prices on their spot markets.[12] Flexible electrified heating enables consumers to capitalise on these low-cost periods, switching to electric heat whenever electricity prices are sufficiently lower than gas.

Industry is not exposed to low electricity price periods by default and often uses fixed-price contracts or structured procurement contracts that purchase volumes of electricity in blocks over time, providing stable averaged prices rather than reflecting spot prices at a given moment. This means that the electricity supplier manages procurement and price risk on behalf of industry, which has its benefits – but it also reduces the value of flexible demand. To capture low or negative price periods, industry needs access to contracts with pricing tied to spot markets. This could be arranged in the form of a hybrid contract where a quantity of power is purchased under a fixed price arrangement to cover a site's base load demand, while the remaining flexible demand uses a contract with prices linked to the spot market.

Recommendations

- Regulators who have not yet fully transposed Article 11 of the Electricity Market Directive and put frameworks in place to enable suppliers to offer dynamic wholesale tariffs, should make this a top priority.[13] Suppliers could be encouraged to design tariffs in a way that passes low wholesale prices through to consumers rather than internalising them with floor prices (a lower limit on electricity prices). There is currently limited precedent for doing this; however, some Nordic suppliers already pass through negative prices.

Time-differentiated network tariffs

Network tariffs are differentiated based on voltage level (i.e., whether a connection is on the distribution network or the transmission network) and often contain two components. The volumetric component reflects the amount of electricity drawn from the grid (kWh) while the capacity-based component reflects the consumer's maximum power demand (kW) within a set time frame. The volumetric component incentivises general demand reduction and the capacity- based component incentivises end-users to reduce their peak demand at all times.

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[12] ACER. (2025). *Key developments in European electricity and gas markets* (*2025 Monitoring Report*). ACER. https://www.acer.europa.eu/monitoring/MMR/electricity_gas_key_developments_2025

[13] Sina, S., Dengler, F., Faber, R., Kocher, D., Pumberger, M., de la Vega, R. & Niewitala-Rej, M. (2024). *Analysis of the implementation of EU provisions for the clean energy transition in selected Member States*. Ecologic Institute. https://www.ecologic.eu/sites/default/files/publication/2024/50153-Implementation-EU-Provisions-for-the-Clean-Energy-Transition-Final-Report.pdf

While the capacity-based component is helpful for managing load during peak hours, it penalises large flexible loads which want to draw power during periods when the grid is underutilised. Loads that drive up peak demand necessitate the development of more infrastructure, which drives up costs, while flexible loads that can avoid peak grid hours can operate within the limits of the grid and do not require additional capacity. The mainstream design of network tariffs does not differentiate between these two scenarios – an off-peak load could face the same volumetric and capacity-based charges as a load that draws the same power during peak grid hours.

Increasingly, countries are updating the structure of their volumetric and/or capacity-based network tariff components to reflect time of use. Time-of-use tariffs react to the level of available capacity on the grid, rising during peak periods and falling when more capacity becomes available.[16] Pricing can be static; can vary according to pre-set time blocks (seasons, days, hours); or can be set more dynamically close to real time, to better reflect system conditions. Figure 2 illustrates how a flexible load might shift a portion of its demand to a low-priced period while using a time-of-use tariff.

Time-differentiated network tariffs in Spain and Germany

Spain has time-of-use components in both the volumetric and capacity components of the network tariff at both the transmission and distribution level, distinguishing between daily peak/off-peak hours, weeks/weekend, and seasonal time of use.[14]

The current German grid tariff strongly disincentivises flexible operations by providing a preferential 90% discount to users that maintain the same load capacity for more than 7,000 hours per year. Discussions are underway to implement time-of-use pricing in Germany.[15] Implementation is not expected before 2029 and will only apply to consumers connected to the high-voltage transmission system.

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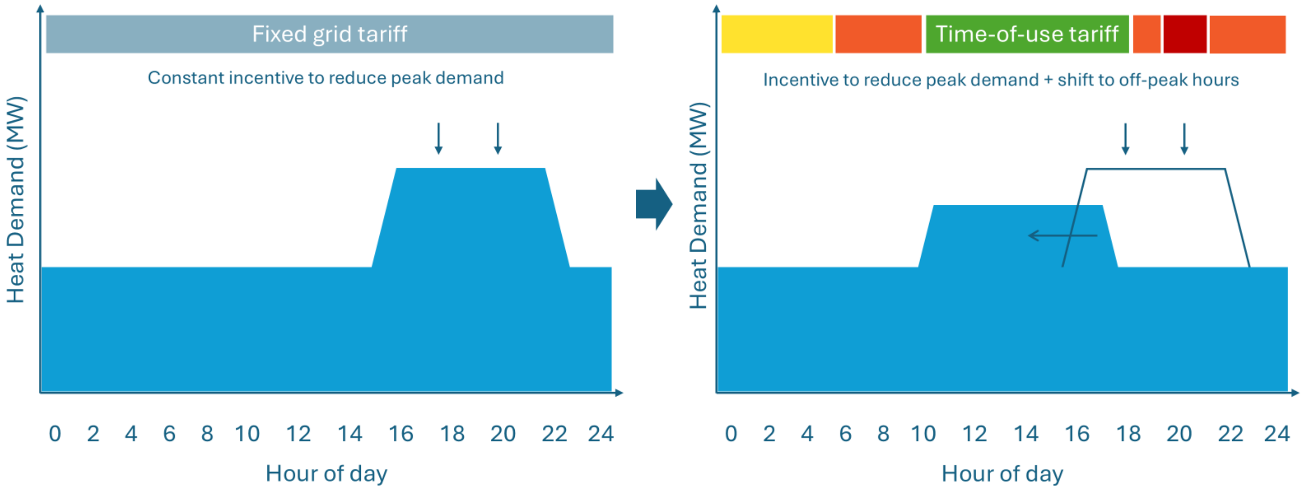
[14] ACER. (2025). *Getting the signals right: electricity tariff methodologies in Europe.* www.acer.europa.eu/sites/default/files/documents/Publications/2025-ACER-Electricity-Network-Tariff-Practices.pdf

[15] BundesNetzagentur. (2025). *Dynamische Netzentgeltkomponente: Orientierungspunkte der BNetzA*. https://www.bundesnetzagentur.de/DE/Beschlusskammern/GBK/GBK_Termine/Downloads/2026/01_2026/14.01./AgNes_Orientierungspunkte_Dynamisierung.pdf?__blob=publicationFile&v=2

[16] Off-peak grid periods can often overlap with low wholesale prices, leading to periods with very low electricity retail prices for consumers.

Figure 2: Illustration of load shifting to midday in response to a low-cost period on a time-of-use tariff



Recommendations

- System operators can design their network tariffs to dynamically reflect constraints and avoid penalising loads that take advantage of available grid capacity during off-peak grid periods. Time-differentiated network tariff components could be considered since these help to shift load away from congested periods without blocking flexible loads during periods of low demand.
- Regulators can consider providing system operators with the ability to offer favourable network charges (e.g., discounts during off-peak times) for certified flexible loads operating within agreed constraints. They should develop a methodology to certify flexibility, potentially based on ability to control loads, maintain sufficient availability, and provide a timely response – this would be similar to the way in which generators are certified. ACER and the European Commission could develop EU-level guidance on this topic.

Access to flexible connection agreements

EU regulation requires national authorities to establish frameworks that allow system operators to offer flexible connection agreements.[19] A flexible connection agreement enables a large electricity user to connect to the grid under the condition that part of their capacity is non-firm, meaning that a portion of the connection capacity can be curtailed under predefined conditions. In practice, this means the site agrees to reduce or limit its electricity demand during periods when the grid is congested. The site can agree a form of compensation in exchange for this constraint, such as reduced network charges. Flexible connection agreements may be layered on top of an existing firm connection, ensuring that critical or non-flexible operations remain protected.

Flexible connection agreement in the Netherlands

The Netherlands has been an early adopter of flexible connection agreements, trialling them in an attempt to manage severe grid congestion in the near term. The Dutch regulatory authority has approved three types of flexible connection agreements:[17] i) fully flexible agreements at the transmission and distribution level; ii) partially flexible agreements on the transmission grid (>110 kV);[18] and iii) time-block-based, partially flexible agreements on the distribution grid (<110 kV).

Recommendations

- National governments and regulators should allow system operators to offer flexible connection models to projects that can demonstrably mitigate congestion. This would enable certain flexibility projects to receive an accelerated grid connection and/or reduced or deferred connection fees in exchange for commitments to reduce load during periods of congestion and for their participation in local flexibility schemes. These benefits could be performance-based, with penalties if obligations are not met. Regulators would be responsible for approving the methodology around performance-based fee reductions, while system operators would be required to implement the accelerated connection process and monitor compliance.

Participation in system services

Flexible electric heating can create additional value through the provision of system services such as balancing and congestion management. Large electric heating loads are well suited for grid services since they can often react faster than thermal generators. A recent study looking at energy-intensive industrial applications found that some sectors can earn a

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[17] Overheid.nl. (2025). *Grid code electricity*. https://wetten.overheid.nl/BWBR0037940/2025-12-01

[18] For the partially flexible agreements on the transmission grid, the capacity charge component of the tariff is waived on the condition that the site's connection capacity can be constrained over an agreed number of hours (up to 15% of the hours in a year). The value of the discount could amount to as much as a 65% reduction in total network costs. Sites are notified that their connection capacity will be constrained 24 hours in advance. TenneT. (2025). *Time bound transport agreement*. https://www.tennet.eu/nl-en/node/3850

[19] European Parliament & Council of the European Union. (2024). *Directive (EU) 2024/1711 of 13 June 2024 amending Directives (EU) 2018/2001 and (EU) 2019/944 as regards improving the Union's electricity market design.* Official Journal of the European Union, L 2024/1711. https://eur-lex.europa.eu/eli/dir/2024/1711/oj/eng

significant extra income stream by offering flexible electricity use to the power grid.[20] Sectors determined to have strong flexibility potential, such as cement and paper, have an estimated earning potential of around €300,000 per year for each MW of flexible power they can offer. The most flexible sites are those that can modulate their electricity quickly and reliably in response to the grid's needs. The precise value of system services to a site is highly dependent on location and industrial sector.

Industrial demand response is legally recognised under EU law; however, access is uneven across Member States. France and the Nordics have relatively advanced approaches to industrial demand response, whereas Member States in Southern and Eastern Europe often have minimal industrial participation.[21]

Recommendations

- Rules for participation in system service markets should not preclude demand-side flexibility resources such as industrial electric heating systems, particularly with respect to the treatment of asymmetric bids and thresholds on bid sizes (see box below).[22]

- The European Commission could consider mandating the development of data standards for submetering heat generation and electricity consumption on demand-side assets such as industrial heating.[23] Sites with submetering would be able to share data with licensed aggregators and system operators (TSOs/DSOs) in exchange for access to flexibility markets (with data safeguards in place). Submetering could be included as a condition for receiving funding under national support schemes, since greater visibility on electricity use can encourage consumers to operate assets in a flexible, system-friendly way.

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[20] smartEn & Compass Lexecon. (2025). *The business case for flexibility provision in energy-intensive industries: Technical and economic assessment for the EU in 2030*. https://smarten.eu/reports/the-business-case-for-flexibility-provision-in-energy-intensive-industries/

[21] smartEn. (2026). Europe's demand-side flexibility reality check: The 2025 Market Monitor and 2025 smartEn Map. https://smarten.eu/news/europes-demand-side-flexibility-reality-check-the-2025-market-monitor-and-2025-smarten-map/

[22] NRAs would be required to approve the modified product specifications and ensure non-discrimination between generation and demand. TSOs and DSOs could be encouraged to publish clear guides for demand response to participate with standardised technology-neutral prequalification procedures (current procedures are designed for generators – not loads). Elements of existing baseline methodologies for demand response baselines (e.g., the French NEBEF system and in the PJM) could be used to guide a harmonised procedure. This issue is likely to be partly addressed in the upcoming Demand Response Network Code.

[23] Similar data frameworks already exist for smart metering, EVs and generator data exchange; industrial heat is one of the few large, flexible electricity end-uses without a standardised EU-level data framework.

Prequalification criteria for system service provision

In practice, industrial assets are often blocked from participating in system service markets due to the limitations of rules that were designed with thermal generators in mind:

- The minimum bid size for an individual industrial site attempting to participate in balancing markets is often prohibitively large (multiple MWs).
- Some ancillary service products require symmetric bidding, i.e., the ability for an asset to increase and decrease load by the same amount if called upon. Achieving this symmetry can be challenging for industrial heating, where load reduction is typically preferred.
- Prequalification procedures have historically been designed for generators, and industrial loads may need to be validated differently, which potentially involves complex and lengthy approval processes.
- To measure demand response for certain system services, a site must establish a baseline of demand. Clear baseline methodologies are important for industrial participants to understand the likely level of revenues and to help settle any disputes. Very few Member States have established clear baseline rules that can be easily implemented by industry.

It is important that these barriers are overcome through regulatory reform to unlock industry’s full flexibility value. Third-party aggregators can help industry to navigate the complexities of participating in flexibility markets by partially managing industry’s assets.

Case study: Exploring the value of flexible electrified heat in Spain and Germany

To explore the current business case for flexible heat electrification, we estimated the investment payback period for hybrid electric-gas heating systems in Spain and Germany. Both these countries have increasing price spreads in wholesale electricity prices and rising system service needs, which makes industrial flexibility an interesting opportunity to explore. We made the following assumptions in our modelling:

- Our analysis modelled a typical mid-sized industrial site with centralised gas-fired boilers and a steam distribution system, which is broadly reflective of the primary heating system present at many of Europe’s light manufacturing sites.
- Two flexible hybrid electric-gas heating systems were modelled: an e-boiler and an ETES system. We chose to model a hybrid system assuming that the modelled site is currently constrained from fully electrifying (due to economics and/or grid constraints) but wishes to make progress on electrifying a portion of its heating.[24]
- We modelled the dispatch of an e-boiler and ETES respectively in response to day-ahead electricity prices, with the site’s heating duty switching between gas and electricity depending on which provided the lowest-cost heat at a given moment in time.[25]
- As a basic proxy for time-of-use network tariffs we applied a % discount to a flat network tariff during off-peak grid hours.
- An optimiser was used to find the ETES storage capacity which provided the best return on investment for this specific modelled scenario.
- The analysis did not estimate the possible additional revenue that could be earned through the provision of system services.

Figure 3 shows the estimated payback year of an investment in the modelled e-boiler and ETES systems. For Germany, our modelling suggests that the expected payback is prohibitively high for both technologies. Implementing time-of-use network tariffs improves the business case; however, even with these measures in place, the return on investment is poor. In the price data used for this modelling, electricity is cheaper than gas nearly twice as frequently in Spain as it is in Germany, leading to investments with faster payback periods, particularly for the system with an e-boiler.

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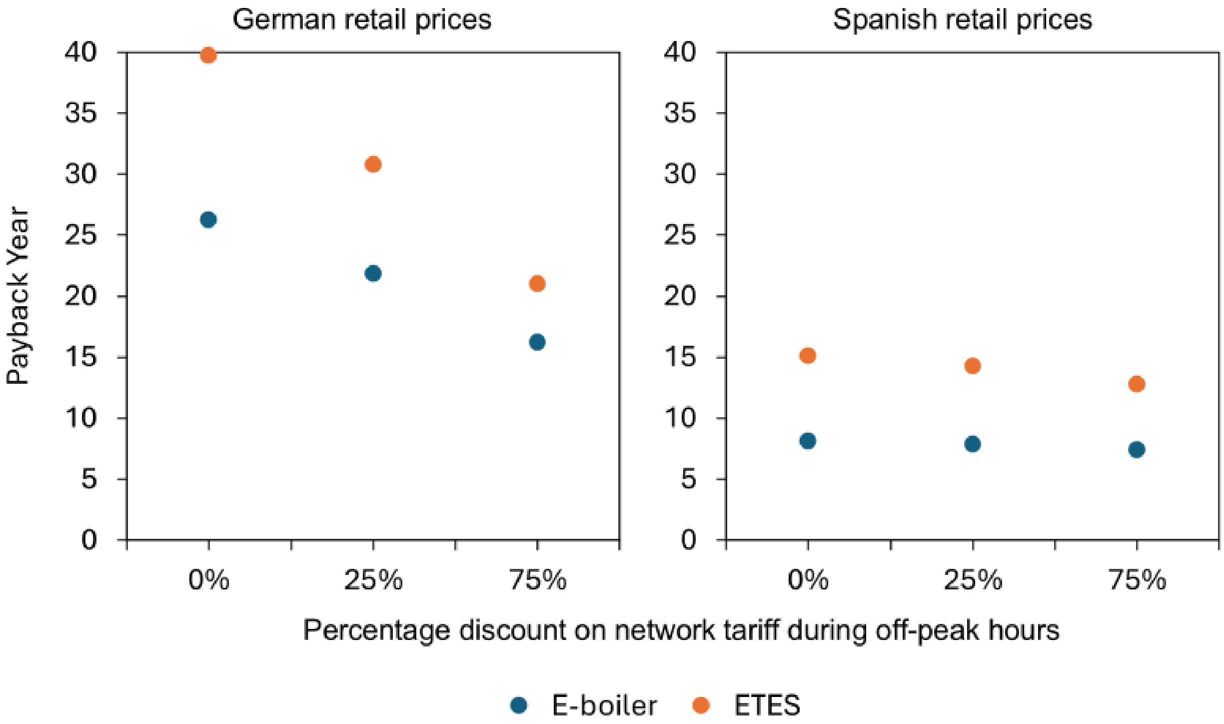
[24] This situation is reasonably common across Europe’s light industrial sites, and many early industrial electrification projects have chosen to maintain some of their existing fossil-fired heating in the near term for operational flexibility, optimising operational costs, and to mitigate any reliability concerns among managers unfamiliar with electrified technologies. Some sites may plan to use a heat pump in the future to meet their constant baseload heat demand while using a flexible electrified technology for peaking.

[25] To simulate hourly variations in electricity wholesale pricing, historical German and Spanish pricing data between October 2024 and September 2025 was used. (EnergyPrice_12.1.D_r3) accessed from https://transparency.entsoe.eu/

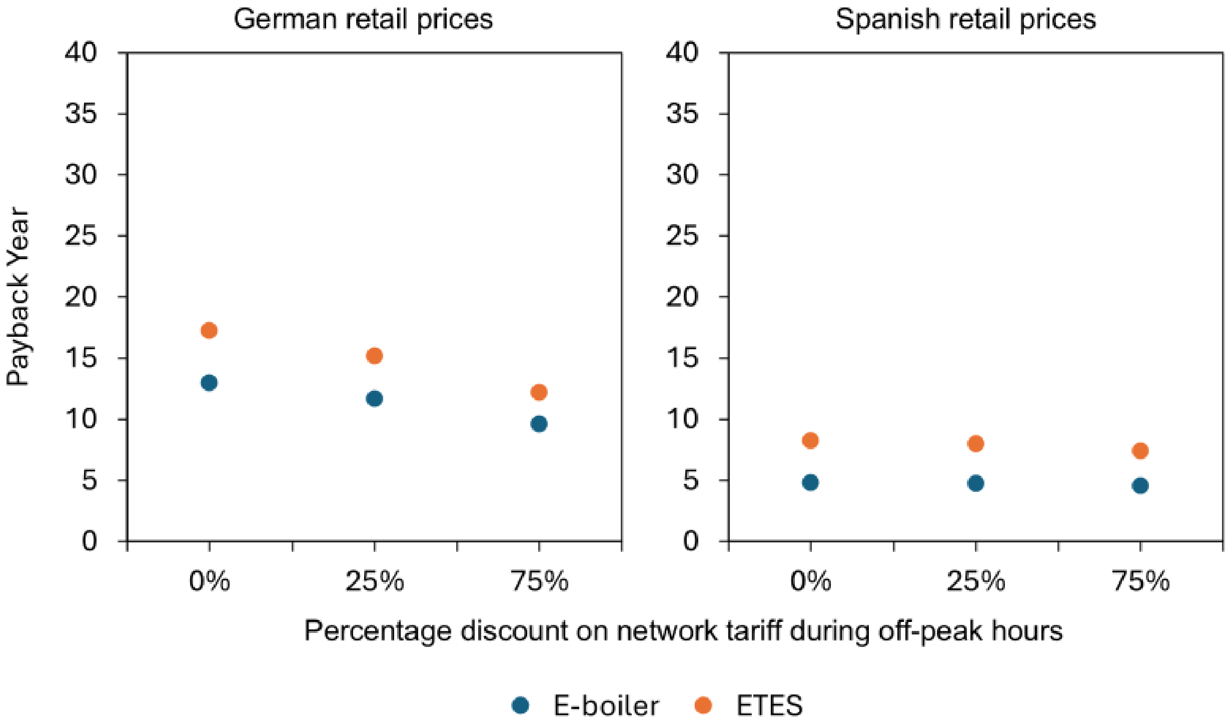
Figure 3: Impact of targeted network tariff discounts on the payback year of investments in flexible heating technologies in Germany and Spain



Multiple countries are considering potential exemptions from taxes and levies for newly electrified loads. An additional scenario was therefore created, where tax (excise, VAT and any generation taxes) and policy levies (CHP support schemes, grid-use levies) on electricity prices were reduced to EU minimum values.

Figure 4 shows that applying exemptions from taxes and levies significantly benefits the business case. However, even under these conditions the payback periods for investments in Germany are still prohibitively long. For a country like Germany where average wholesale electricity prices are high, electricity prices are rarely lower than gas even with reduced network tariffs and exemptions from taxes and levies. This underscores the importance of opening access to system service markets for industrial assets, since investments in industrial flexibility need to stack value from both energy pricing and system services to become competitive.

Figure 4: Impact of a range of targeted network tariff discounts on the payback year of investments in flexible heating technologies (without revenue from system services) in Germany and Spain with taxes and levies on electricity reduced to the EU minimum level



E-boiler or electro-thermal energy storage?

ETES systems have higher upfront costs than e-boilers due to the need for additional components (an energy storage medium) and a higher-capacity grid connection. To achieve the same payback period as an e-boiler, an ETES system would need to make greater savings on energy costs – and these depend on a site's specific heat demand profile and its energy prices. The results of our modelling (Figures 3 and 4) show that e-boilers usually have a shorter payback period than ETES systems, but the reverse could also be true for sites with different conditions. For example, if a significant portion of a site's heat demand regularly falls within periods with high electricity pricing, an e-boiler – which acts as a real-time load – might rarely be dispatched and might struggle to provide cost savings. An ETES system at the same site might be able to charge up during lower price periods and dispatch heat when electricity prices are high, providing cost savings. Choosing the most cost-competitive technology depends on multiple site-specific factors (including potential revenue from system services) and should be evaluated on a case-by-case basis.

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