FROM GAS TO GRID

Electric boilers and Thermal Energy Storage: two competitive levers to decarbonize industrial heat

E-CUBE STRATEGY CONSULTANTS

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Executive Summary - Electric boilers and thermal energy storage are becoming a pragmatic decarbonisation and flexibility lever

Electric boilers (e-boilers) and (Electro-)Thermal Energy Storage (TES/ETES) are emerging as a mature and increasingly competitive solution to decarbonise industrial heat in Western Europe. Their value no longer lies solely in fuel switching: when integrated into a broader flexibility strategy, e-boilers become a power-market-exposed asset at the intersection of electricity and thermal systems, able to monetise power market volatility.

Structural changes in European energy markets have materially improved the business case for electric heat, notably through:

i) a step-change in gas prices and their exposure to geopolitical risk,
ii) higher carbon costs under the EU ETS,
iii) increasing electricity price volatility driven by renewable penetration.

Together, these dynamics create new windows of competitiveness for electric heat and enhance the value of flexible electricity consumption.

While full standalone electrification remains economically challenging in most configurations today, hybrid solutions combining e-boilers with existing gas assets can already **deliver material CO_2 reductions with acceptable returns in favourable contexts**. In addition, **ETES can increase both decarbonisation impact and hedging value** against commodity stress events. These assets represent a significant share of the future flexibility potential in the industrial segment.

Although less efficient than heat pumps, with a coefficient of performance close to 1, e-boilers and ETES remain highly relevant for industrial heat decarbonisation. Their attractiveness stems from simple equipment design, relatively low CAPEX, the ability to reach high temperature levels, and their fit with power systems increasingly characterised by renewable surpluses and curtailment, where the ability to absorb low-cost electricity can outweigh conversion-efficiency considerations.

This point-of-view explains why e-boilers and ETES are emerging now, under which technical and economic conditions they make sense, and what they imply for industrial players and the broader ecosystem (aggregators, developers, utilities and system operators), with a particular focus on Western Europe and France.

1. Energy markets are increasingly rewarding flexible assets such as e-boilers and TES

Decarbonising heat is a key challenge for the industry sector. Today, around **two thirds of industrial energy consumption is used in the form of heat**, still largely produced from fossil fuels – mainly natural gas (~40% of energy consumption for heat processes) – cf. Figure 1.

Despite the availability of mature electrification solutions, **market conditions long failed to provide strong incentives** for industrial players to electrify heat production.

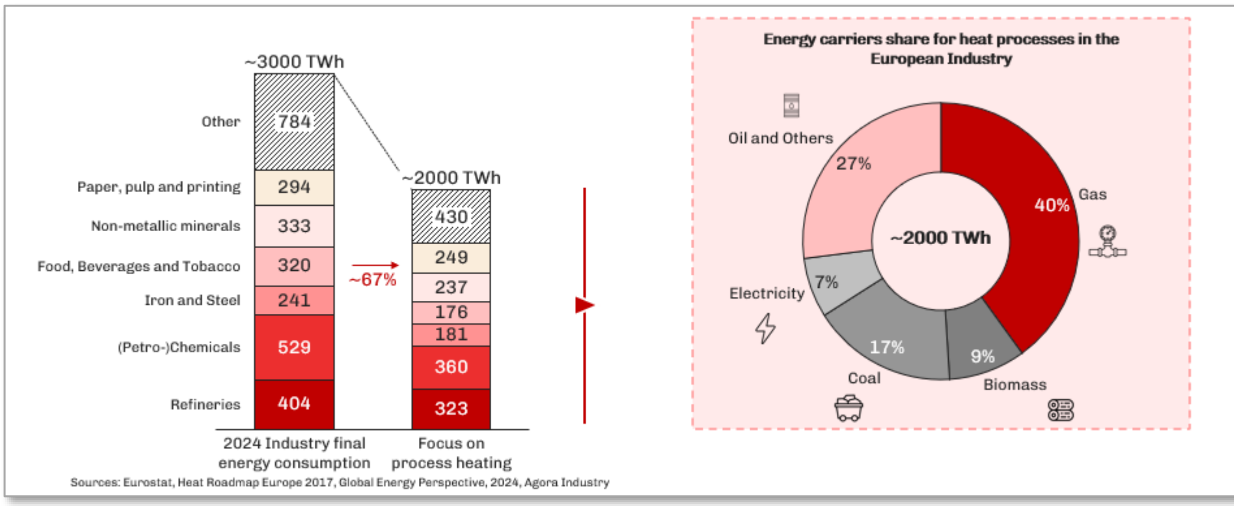


Figure 1 - Final energy consumption without material use – EU 27 + UK industry [TWh; 2024]

Until 2022, the market context was structurally unfavourable to electric heat for a combination of well-identified reasons:

- **Natural gas prices** were low and relatively stable (15-25 €/MWh[1] for large industrial consumers), supported by highly competitive pipeline imports from Russia;
- **Carbon prices under the EU ETS** were low and stable (~10-40 €/tCO_2[1)]), i.e. an incremental cost of **~2-8 €/MWh$_{th}$** for gas-based heat, before free allocation effects.
- **Electricity market volatility** and flexibility value were limited, providing few opportunities for flexible electric loads to (i) regularly capture very low prices and (ii) monetise flexibility on reserve / balancing markets.

[1] Over 2018-2021

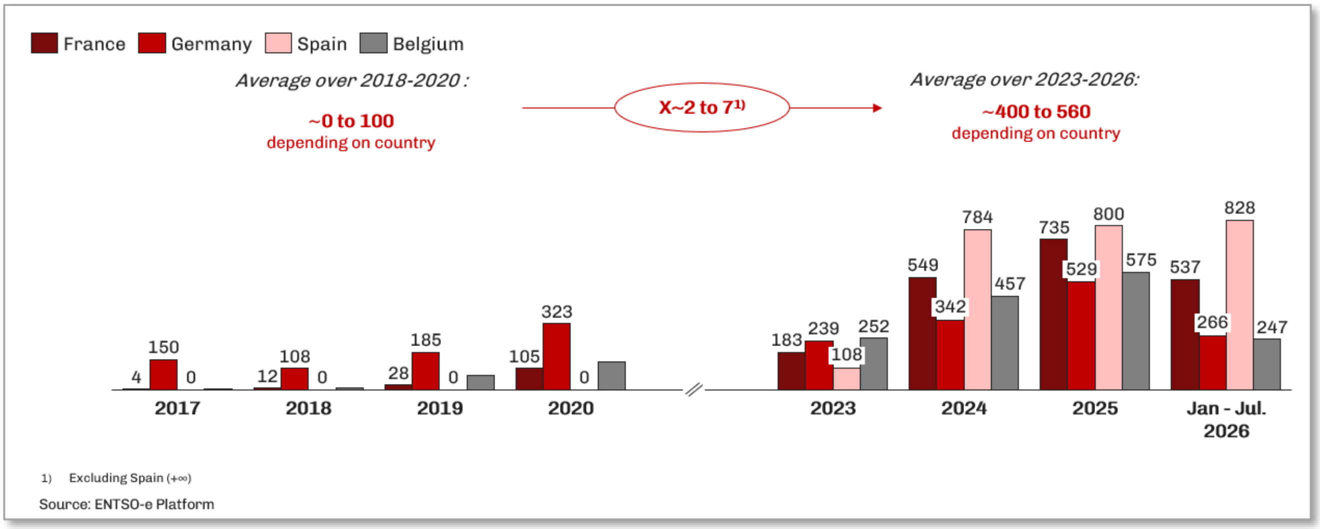
Since 2022 — and further reinforced by renewed geopolitical tensions — this environment has changed profoundly, structurally improving the case for flexible electricity consumption. Continued reliance on fossil heat, and gas in particular, has lost much of its former attractiveness as:

- Gas prices are now structurally higher, with industrial supply costs typically ranging **~30–60 €/MWh** and with significant volatility spikes during crisis episodes,
- The perceived "energy security" benefits of LNG diversification have been challenged by geopolitical events, re-highlighting commodity price risk.
- Carbon prices under the EU ETS have doubled, plateauing around **50–100** €/tCO_2 since 2022 and increasing the variable cost of gas heat by **~10–20 €/MWh$_{th}$** before free allocation.

Conversely, electrification through flexible assets has become structurally more attractive:

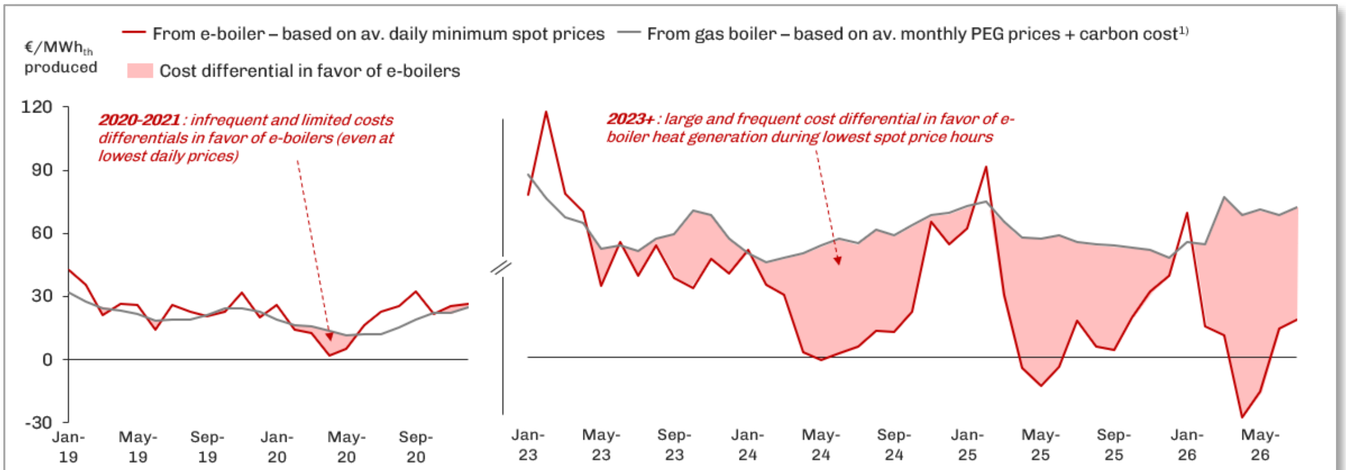
- Growing renewable penetration increases the frequency of very **low or negative electricity prices** and increases **short-term volatility**, thereby raising the value accessible to flexible consumers (cf. Figure 2);
- Electrification also increasingly takes a strategic dimension, acting **as a hedge against fossil price shocks**. In France in particular, growing low-carbon generation combined with sluggish demand has contributed to a progressive decoupling between electricity prices and gas prices.

Figure 2 - Number of zero or negative spot price hours in selected European countries [#/year, 2018-26]



As a result, heat production using e-boilers and TES, based solely on electricity price arbitrage — even without monetising flexibility services — can now be competitive with gas boilers for up to ~2,000 hours per year in several Western European markets (cf. Figure 3).

Figure 3 - Variable cost of heat generated from a gas boiler vs. by an e-boiler running on minimum daily power prices in France[1)] – excluding network costs and taxes



1) Cost assumptions : no network costs nor taxes assumed. CO2 price assumptions : 0.2tCO2/MWh gas emission factor, carbon price of 25€/tCO2 over 2019-20 and 70€/tCO2 over 2023-25.

Source: ENTSO-e Platform

Beyond individual business cases, these assets also generate material system-level value:

- **They absorb renewable generation surpluses**, reducing curtailment while also limiting modulation costs for non-subsidised generation assets (e.g., nuclear);
- **They support** higher / non-negative prices in surplus hours and can reduce public support costs linked to renewable CfDs;
- **They add** flexible demand to balancing and reserve markets, contributing to lower system balancing costs;
- **They improve** national trade balances by substituting fossil imports with consumption of domestic electricity.

2. E-boilers and TES are mature, modular and can substitute fossil heat "like-for-like" in hybrid configurations

E-boilers are now **comparable to gas boilers in many industrial utility applications in terms of CAPEX and conversion efficiency**. They typically offer very fast ramp-up capabilities, making them particularly suitable to follow power market signals without disrupting industrial processes (cf. **In many** cases, **e-boilers are not deployed as a full replacement for gas assets** but as a complementary asset operated in parallel with existing gas boilers. This hybridisation preserves operational resilience while enabling material CO_2 reductions and exposure to low-price electricity windows.

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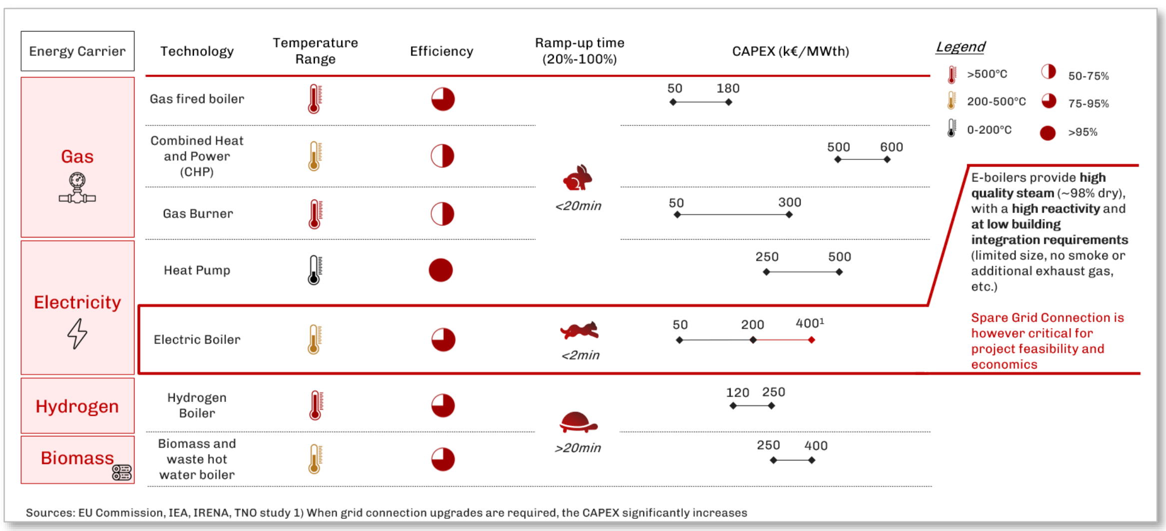
Figure 3- Heat production technologies characteristics, by temperature range

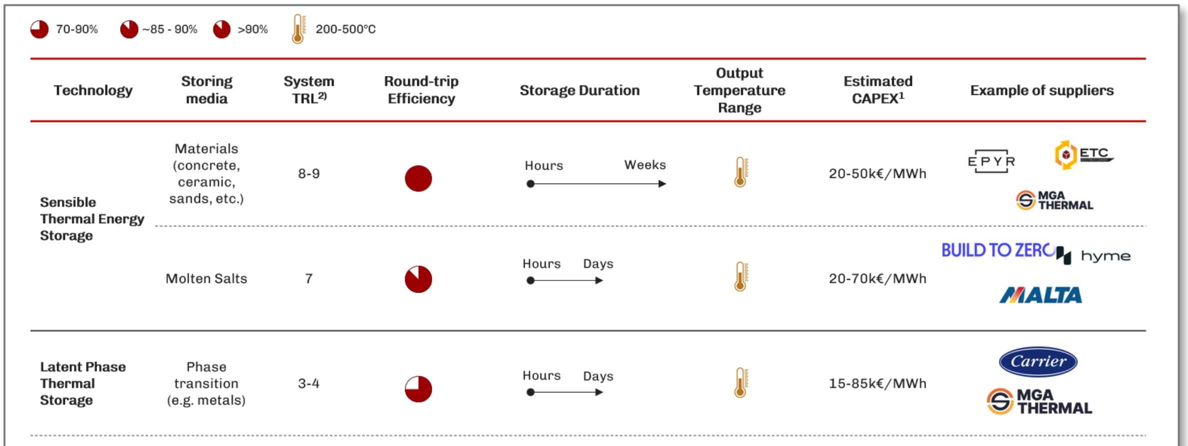


E-boilers can be combined with thermal energy storage (TES / ETES). In some configurations, ETES may also be installed independently, with electricity directly converted into stored heat – cf. Figure 5.

Compared to electrochemical batteries, thermal storage remains relatively inexpensive on a stored-energy basis (indicative CAPEX: ~**[50 €/MWh$_{th}$]** for TES vs **[150–200 €/MWh$_e$]** for BESS), enabling heat produced during low-price hours to be delivered later under baseload conditions. ETES can:

- **Increase decarbonisation impact** by extending the substitution window of gas heat;
- **Increase flexibility value** by allowing larger load shifts without process disruption;
- **Strengthen the "hedge" value** during commodity stress events by reducing exposure to gas over wider time windows.

Figure 4 - Characteristics of main Thermal Energy storage technologies



Source : European Association for Storage of Energy, Energy Transition Expertise Centre, European Commission 1) TES CAPEX depends primarily on the storage capacity in MWh. If the storage also comprises a heat production system, there is an additional cost similar to those of e-boilers in €/MW 2) For power to heat technologies only – and not power to heat to power

3. In complement to existing heat assets, e-boilers can deliver material CO_2 savings with payback time of 3 to 5 years

Three archetypal configurations can be distinguished, each with distinct economic and environmental performance profiles (cf. Figure 6):

- **Standalone electric boiler** (full replacement of gas heat);
- **Hybrid** gas + electric boilers (e-boiler operated alongside gas assets);
- **Hybrid** gas + ETES (intermediate pathway increasing CO_2 savings while limiting profitability dilution).

Standalone electrification (without ETES) **maximises CO_2 abatement but is often not profitable at scale** in current market conditions. It can nevertheless become viable in specific contexts - notably when the industrial player applies a high internal carbon price (reflecting strong decarbonisation ambition) and/or faces high effective carbon exposure (e.g., limited free allowances), and where electricity taxes and grid fees are favourable.

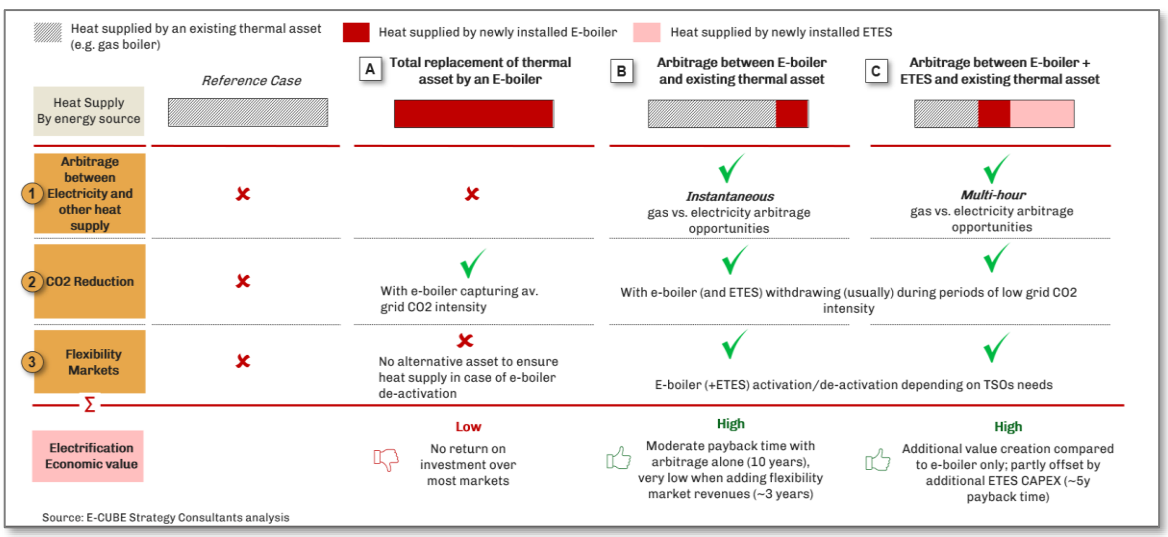
Hybrid configurations typically deliver the most attractive risk-return profile in favourable cases. In such configurations, e-boilers/ETES can generate acceptable returns while delivering material CO_2 savings:

In favourable contexts, these hybrid configurations can deliver:

- **CO_2 savings**: **~20–40%** depending on operating strategy and electricity mix;
- **IRR**: **high-single to double digits** in favourable contexts (depending on CAPEX, taxes, grid fees and captured flexibility value);
- **Payback:** compatible with industrial investment criteria in best-case configurations (< 5 years payback time). **This payback time can be even shorter when the eBoiler is used for flexibility (aFRR, mFRR, intraday)**

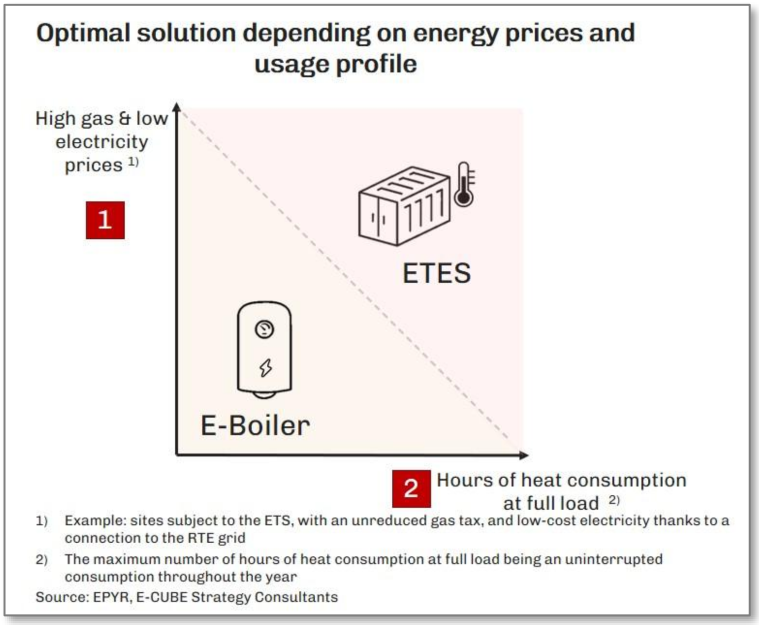
Adding thermal storage can increase CO_2 savings while limiting the deterioration in profitability versus the pure hybrid case, and can also mitigate "carbon lock-in" concerns by expanding the share of heat that can be shifted away from gas.

Figure 5 - Valorisation markets and economic performance depending on e-boiler / ETES configuration



The higher the cost of gas-based heat and the utilisation rate of the heat asset, the more attractive ETES becomes relative to a standalone e-boiler, as higher captured value can compensate for the additional CAPEX.

Figure 6 - Competitive Advantage of E-boiler and ETES



Additional value from e-boilers and ETES can also be captured through ancillary services and balancing markets, including aFRR, mFRR and intraday optimisation. These revenue streams can enhance project economics and further shorten payback periods. The effective flexibility potential of an e-boiler also depends on the ability of the gas boiler to offset variations in heat output from the e-boiler.

4. Profitability is highly sensitive to site-specific characteristics and context, with four cumulative conditions defining attractive use cases

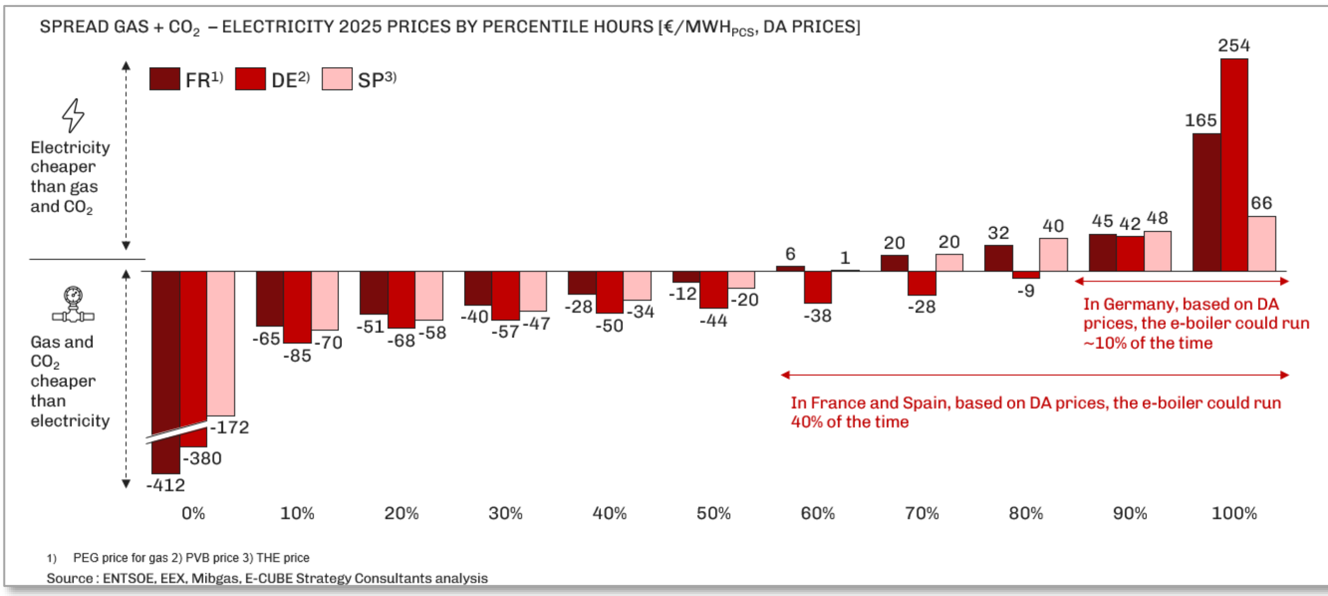
E-boiler economics depend strongly on both country context and site specifics. The most attractive cases typically combine four cumulative conditions:

- **Available grid connection capacity** (limiting reinforcement costs and delays).
- **Meaningful carbon pricing exposure**, such as the EU ETS market and/or high internal carbon price;
- **Low variable electricity surcharges** above wholesale power prices, notably taxes, and energy-based grid fees.
- **Baseload heat demand,** especially outside the winter season.

These criteria create **sharp differentiation across geographies and sites**.

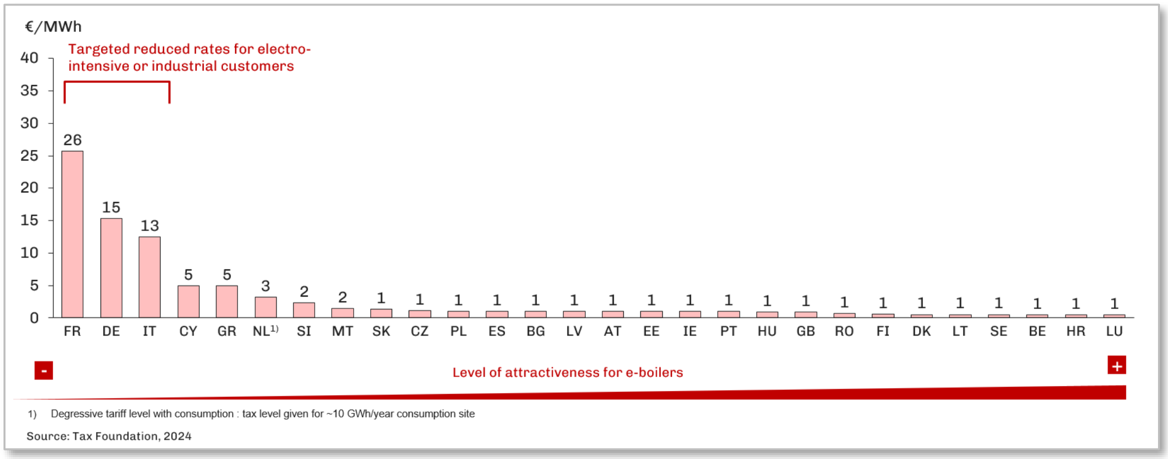
From a geographical perspective, **electricity-gas spreads and electricity price volatility are decisive drivers of value.** Markets where the marginal power price is too frequently set by carbon-intensive assets are structurally disadvantaged. Germany is therefore often less attractive than France or Spain in this respect.

Figure 6- Spread {(gas + CO2) – electricity}, by percentile hours [€/MWh$_{PCS}$, DA prices, 2024]



Gas and electricity taxation is another key driver. In Western Europe - and particularly in France - electricity can be more heavily taxed than gas outside specific regimes, which can erode e-boiler competitiveness unless the site benefits from reduced rates (e.g., electro-intensive profiles). Conversely, parts of Northern and Eastern Europe may offer more favourable electricity tax structures.

Figure 7 - Level of electricity taxes for business use in selected EU28 countries [2024]



From a site perspective, **the most attractive targets tend to be industrial sites with baseload heat demand and significant electricity consumption** (indicative threshold: >~10 GWh/year). These sites are often connected to the transmission grid or high-voltage distribution networks, allowing them to benefit from lower energy-based grid fees, particularly when exposed to the EU ETS.

5. E-boilers and TES reshape choices for industrials, aggregators and grid operators

The deployment of electric boilers and TES represents a tangible opportunity for multiple stakeholders involved in their installation and value capture:

- **Industrial heat consumers** can reduce heat costs in favourable hours, add redundancy in heat production assets, and partially decarbonise their processes;
- **Aggregators, developers and integrated utilities** can develop a scalable flexibility asset class and a new growth avenue at the intersection of flexibility markets and industrial decarbonisation.
- **Grid operators** can benefit from additional flexibility that helps contain balancing costs and supports renewable integration.

For industrial players, capturing the opportunity typically requires:

- **Building a clear view** of the site's future heat demand trajectory and electricity demand;

- **Assessing site-specific constraints** (heat delivery ramp-up constraints, available connection capacity, effective carbon cost, electricity and gas grid fees and taxes, electricity and gas supply contract structure, etc.);
- **Benchmarking** e-boilers against alternative decarbonisation options, considering both cost and operational constraints;
- **Defining** an appropriate development and value-capture approach aligned with internal capabilities and risk appetite.

Development models can range from fully integrated approaches (maximising value capture but requiring internal resources and market exposure) to fully outsourced schemes (third-party investment and operation), with intermediate partnership configurations (e.g., value-sharing contracts, co-investment, optimisation partnerships).

For aggregators, developers and integrated utilities, building a specific offer around e-boilers typically requires:

- **Defining target** “site archetypes” based on the main attractiveness criteria (grid capacity, baseload heat, carbon exposure, electricity surcharges).
- **Estimating market potential** and value within the addressable portfolio, and prioritising segments based on attractiveness and accessibility;
- **Designing offer(s)** adapted to each segment (commercial proposition, contract structure, risk allocation) and allocating prospecting resources accordingly.

For TSOs/DSOs, scaling e-boilers also raises questions around their integration into the flexibility landscape, including: (i) assessing flexibility potential and activation costs, (ii) identifying conditions for deployment (connection availability, fee structures), and (iii) incorporating such assets into long-term system planning and flexibility outlooks.

Conclusion - E-boilers can become a no-regret lever if tariffs and taxes align with system value

Electric boilers and Thermal Energy Storage are becoming mature and pragmatic levers to decarbonise industrial heat. Their competitiveness is **structurally supported by the transformation of Europe's electricity and gas systems:** more volatility in an increasingly low-carbon and intermittent power mix, combined with higher and more volatile gas prices and carbon costs.

The most attractive use cases are typically **hybrid configurations** deployed for industrial heat consumers with baseload heat demand, meaningful electricity consumption (>~10 GWh/year), exposure to carbon pricing, and favourable grid and electricity surcharge conditions - within Western Europe, with France offering strong technical relevance but a more mixed competitiveness picture due to taxation and tariff structures.

As renewable curtailment increases sharply across European power systems, these assets are expected to gain momentum due to their ability to convert otherwise under-utilised electricity into useful industrial heat. This requires **continued reflection by all ecosystem players** on the prioritisation of use cases, operational and contractual set-ups for value capture, and - for regulators and grid operators - on how grid tariffs, grid connection development and electricity taxation (vs. gas) can better align industrial electrification with system-level value.

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