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THE ITALIAN CLIMATE CHANGE THINK TANK

ELECTRIFICATION OF INDUSTRIAL HEAT:
The key to a sustainable and competitive industry

REPORT
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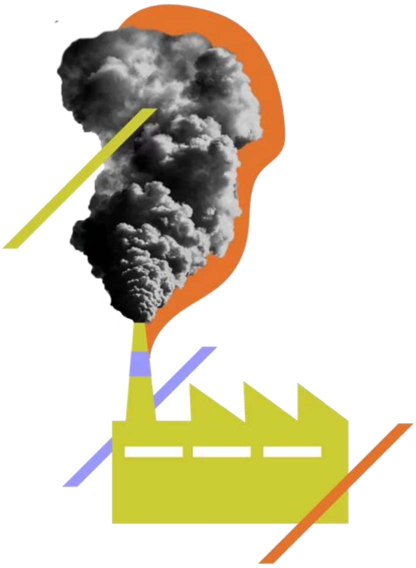

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EXECUTIVE SUMMARY

Today, industry is responsible for approximately 20% of greenhouse gas emissions in the European Union.

Decarbonising the industrial sector requires a targeted approach, with solutions that in most cases must be tailored to meet the needs of each industry. However, these solutions are not always readily available or affordable. This also applies to cross-sectoral solutions **such as the direct electrification of industrial process heat**. Nevertheless, electrification remains the **most competitive option and the only one capable of aligning decarbonisation objectives with energy security needs.**

Electrification of process heat in Italy and Europe

In Italy, 68% of process heat demand is met using fossil fuels (this share rises to 75% in the EU). Of this demand, 31% is for low and medium temperature process heat (up to 200°C), a percentage that increases to 45% when including space heating, which can already be efficiently electrified with existing technologies.

A previous study by ECCO assessed the potential for electrifying processes below 150°C and the corresponding emission reduction potential. Although the research showed significant emission reduction potential (up to 16MtCO_{2eq}), barriers to the diffusion of electrification were identified.

Feasibility study for the textile and food sectors

This report presents the results of a specific **feasibility study** on the electrification of two key sectors in the Italian manufacturing industry: food and textiles.

Both sectors excel in terms of profits and exports. They are predominantly composed of Small and Medium-sized Enterprises (SMEs account for 61.8% - food - and 81.9% - textiles - in terms of turnover). Moreover, both sectors use process heat at temperatures below 150-180°C and can therefore be electrified with existing technologies.

The study was conducted using a sector-specific energy model designed by ECCO, using the open-source platform Osemosys. The analysis was carried out by validating literature-based hypotheses through interviews with experts from companies, suppliers of electrical technologies and process machinery, and energy service providers. **The study presents different cost-effectiveness scenarios for replacing natural gas with electrified solutions.** Starting from the most recent sectoral energy balances and modelling the energy transformations of carriers (gas, electricity) from their entry into the two sectors to final services (e.g. low or high temperature drying, with or without steam), the model optimises cumulative long-term costs, considering the evolution of CapEx and OpEx for technologies and in relation to projected gas and electricity price trajectories.

The different price scenarios of energy carriers and heat production technologies drive the diffusion trajectories of technological innovations and their impact on electrification adoption. This approach provides for an electrification scenario of industrial processes over time, based solely on economic variables, which makes it possible to **inform policies on how to intervene to facilitate electrification in terms of efficiency, environmental, and competitiveness objectives**.

The proposed energy carrier price scenarios exclude the fiscal and parafiscal components of tariffs, while including estimates of the ETS1 mechanism costs in electricity pricing and ETS2 for gas.

The results of the scenario analysis indicate that:

1. **Electrifying process heat below 80°C is the most cost-effective solution by 2025, based on current electricity and natural gas prices.** Electrifiable demand in this temperature range is limited to about 10% of thermal uses, excluding space heating. In this case, the role of electric technologies saves 1.7 Mton CO_2 and 0.8 billion Smc.
2. **For temperatures above 80°C and processes requiring steam, the model indicates that the price differential between electricity and gas**, defined not only by the relative prices of the two carriers but also by the efficiency of the technologies, **prevents the recovery of the higher investment costs of electrification technologies until at least 2040.**
3. **By 2040, the model sees an economic benefit in the complete electrification of heat processes.** This is the result of:
    a. the progressive decoupling of electricity prices from gas prices, where electricity prices converge towards the LCOE of photovoltaic plants and their storage infrastructure, decoupling from ETS1 charges;
    b. gas price forecasts, on which there is a progressive increase due to the growing role of ETS2;
    c. the expected reduction in investment costs of process electrification technologies.

However, the scenario presents a suboptimal technology mix in terms of energy efficiency. This is because the substitution of gas-powered alternatives with electric ones is driven solely by the price of the two carriers and occurs when the ratio between the price of electricity and gas is 1.1. Therefore, electric technologies with lower CapEx and lower efficiency are adopted.

To accelerate the adoption of electrified solutions, the impact of incentivising policies on energy efficiency, investment support and their cost were analysed.

In particular, a reduction of the Weighted Average Cost of Capital[1] to 4%, compared to the 10% assumed in baseline simulations, **with financial policies and the introduction of a 50% capital incentive on the investment costs of high-efficiency electrical technologies,** leads the model to adopt heat pumps **five-years** earlier, achieving an electrification rate of 86% by 2035 and long-term cost savings.

According to the analysis, the cost of these public support policies would amount to 2.3 billion euros for the state between 2025-2040.

Finally, solutions based on the use of biomethane were simulated. According to the scenarios, **biomethane does not appear competitive compared to electrification** as a decarbonisation solution for the food and beverage and textile sectors. Indeed, the price of biomethane is estimated to be in line with that of hydrogen, for which it is a direct substitute in processes that are difficult to electrify.

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[1] WACC - Weighted Average Cost of Capital

These results are confirmed by case study analyses conducted on six companies, four of which are in the food sector (three cheese factories and one brewery) and two in the textile sector, where electrification of low and medium temperature process heat is always technically feasible.

In the case studies, where fiscal and parafiscal charges applied to electricity and gas tariffs, such as general system charges and excise duties, are also considered, the economic advantage of electrification is nullified even in processes below 80 °C. In fact, the weight of the fiscal and parafiscal components in the tariffs absorbs the benefits of the higher efficiency of heat pumps compared to the use of gas.

This condition is amplified when considering that, in industries, heat is supplied by the same technology for all processes, including space heating. These infrastructural constraints, common in existing fossil fuel-based systems, require upgrades or modifications to existing machinery and a redesign of energy supply system layouts to accommodate the implementation of technologies supporting electrification.

Moreover, a fragmented legislative framework that, while supporting energy efficiency, also incentivises the installation of gas-powered technologies, such as combined heat and power plants, increases the risk of technological lock-in.

The analysis results indicate that, under existing conditions, there is no business case for the electrification of industrial process heat, even with the adoption of the most efficient solutions already on the market.

Therefore, an integrated and coherent policy framework at the European and national level is needed to enable the adoption of these solutions, which support energy security and the competitiveness of the production system in the medium and long-term.

These levels should reinforce each other, maximising the adoption of high efficiency electrification as a solution for decarbonisation, energy security and industrial competitiveness.

This framework should include:

1. **The adoption of an explicit electrification target for industrial process heat** in the EU Electrification Action Plan and resulting legislation. This would provide certainty to investors. The Clean Industrial Deal already defines a cross-sectoral target of 32% by 2030 and identifies electrification as a solution to address the continent's higher energy costs related to fossil fuel imports. This solution could also unlock the potential for the deployment and development of technological solutions in supply chains where the EU seems well positioned, as well as stimulate investment in energy consumption.
2. A regulatory framework that favours electrification, which should:
    a. **Ensure the diffusion of renewable energy in the electricity market with mechanisms that deliver a consumer price that corresponds to the costs of renewable technologies** by closely monitoring progress and promptly removing potential bottlenecks.
    b. **Allow consumers to benefit from the cost and security advantages of renewable energy production** by facilitating the decoupling of electricity and gas prices.
    c. **Review imbalances between electricity and gas tariffs at the national level to remove current barriers to the integration of energy systems through industrial**

process electrification. This would ensure that the fiscal and parafiscal components of tariffs are harmonised with the effects of ETS1 and ETS2 market instruments to deliver a correct impact on final costs in relation to the energy content and CO_2 emissions of different carriers.

d. **Expand and modernise electricity transmission and distribution networks** to accommodate increased demand and respond promptly to connection requests.
e. **Facilitate the creation of lead markets for decarbonised products** through a range of policies, including fiscal incentives and green public procurement, promoting demand for both electrification-enabling technologies and products from decarbonised production.

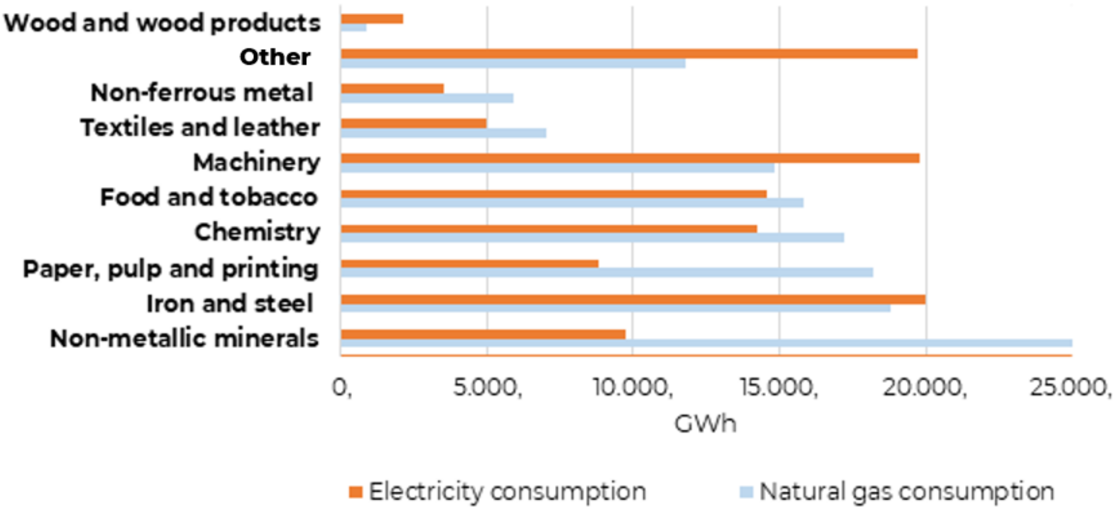
Two basic elements must be considered when developing a policy framework:

1. The development of **skills** and a **qualified workforce** capable of developing new electrification technologies, designing their implementation within industrial sites and handling the complexities involved in assessing the energy profile of processes, installation, operation and maintenance of these solutions. Therefore, despite being mature, electrified solutions still require support for workforce training.
2. The development of a **financial strategy**, including the allocation of dedicated funds for industrial electrification under the **European Competitiveness Fund**, a more stringent allocation of **ETS1 and ETS2** revenues, clear conditions for **state aid** that ensure adequate resources for the demonstration of innovative direct electrification solutions, and the development of smart grids from the **Innovation Fund**, in particular for small-scale projects and projects involving SMEs.

1 INTRODUCTION

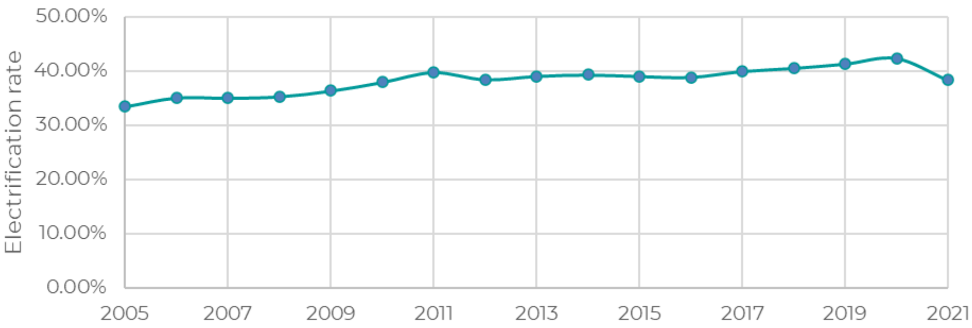
The Italian manufacturing industry, whose production ranks second in Europe and eighth in the world[2] , faces specific challenges in decarbonising its energy consumption. In 2021, the sector accounted for about 22% of national direct greenhouse gas emissions, equivalent to 85.4 $MtCO_{(2eq)}$[3]. Of this, 63% was linked to the direct combustion of fossil fuels (primarily natural gas[4]) for the production of heat in industrial processes (Figure 1).

Figure 1 - *Final consumption of electricity and natural gas by industrial sector. Eurostat data compiled by ECCO.*



Electrification is one of the main strategies for decarbonising heat production in industrial processes[5]. In 2021, the electrification rate of final energy consumption in industry was 38.3%[6] . However, the rate has remained relatively stable since 2005, as shown in Figure 2.

Figure 2 - *Electrification rate of Italian industry (ECCO elaboration from JRC IDEES, 2023)*



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[2] UNIDO data for 2022, measured in US dollars at constant prices 2015

[3] ECCO elaboration based on UNFCCC 2022 data. The share rises to 31% if emissions from electricity use are taken into account.

[4] In 2021, natural gas will account for 39% of final energy consumption in industry. ECCO elaboration based on the Eurostat Energy Balance Industry 2022 and the UNFCCC database.

[5] Frahunhofer ISI 2024, Eurelectric 2024, McKinsey 2023, European Commission Impact Assessment for Target 2040

[6] JRC IDEAS, 2023

Sectoral analyses play a crucial role in understanding sectoral needs and perspectives within the decarbonisation process, ensuring that Net Zero objectives align with the competitive positioning of both existing and emerging supply chains. This paper explores industrial processes with electrification potential and the technical and economic conditions required to make this feasible. By providing quantitative data through scenario analyses and case studies, this work aims to inform national and European industrial policies. These currently lack clear electrification targets and do not specify a clear emission reduction strategy for the manufacturing sector, especially for those industries that fall under the Effort Sharing Regulation (ESR) reduction target assigned to Italy, which often includes less energy-intensive industries and small and medium-sized enterprises.[7]

Italian industry has some distinctive features compared to other European countries. In fact, small and medium-sized enterprises represent the core of the country's industrial ecosystem, accounting for 57% of added value and 17% of national employment[8]. To establish a knowledge base for this study, in February 2024, ECCO conducted a simplified top-down modelling exercise to assess the potential of direct electrification of heat in industrial processes[9]. In particular, this focused on sectors with the highest and most immediately exploitable potential, such as those falling within the scope of the ESR. Based on literature data[10], in 2021, total heat consumption below 150°C was 81.4 TWh, with an associated emission reduction potential of 8.3MtCO_{2eq} by 2030[11] (Figure 3). The use of low and medium temperature process heat (below 150°C) was mainly concentrated in specific sub-sectors such as food and beverage, paper and the so-called 'other' sectors, including textiles, leather and machinery. The main heat demand in these sectors comes from hot water and steam used for industrial processes. The study also found that all industrial sectors share a common potential for electrifying space heating, which accounts for 17% of total final heat consumption (about 13.8 TWh in 2021).

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[7] Furthermore, the National Energy and Climate Plan (NECP) falls short of the Effort Sharing Regulation (ESR) reduction target assigned to Italy, aiming for a -40% reduction instead of -43.7% from 2005 levels. Emissions from the manufacturing sector account for about 13% of the national Effort Sharing target.

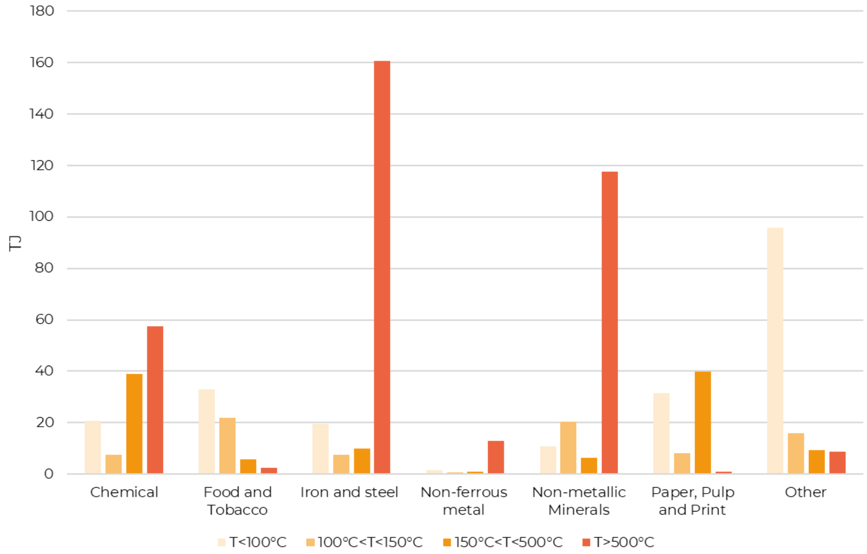
[8] Elaboration on 2019 ISTAT data

[9] Industry and electrification, strategic opportunities for the National Energy and Climate Plan, ECCO, 2024

[10] Data refers to 2021. ECCO elaboration based on Kosmadakis, Georg; 'Estimating the potential of industrial (high temperature) heat pumps for exploiting waste heat in EU industries', Applied Thermal Engineering, 20 April 2019', Applied Thermal Engineering, 25 June 2018.

[11] A conservative estimate assumes that 50% of this heat will be electrified by 2030 and that all heat consumption will come exclusively from natural gas.

Figure 3 - *Final thermal energy consumption of Italian industrial sectors by temperature level in 2021*[12]



Building on this foundation, this work aimed to develop a sectoral analysis on two key sectors of the Italian manufacturing industry: food and textiles, which are characterised by low and medium temperature process heat and low thermal energy demand.

A scenario analysis was then conducted using a computational model to examine how the relationship between the main components of gas and electricity prices in Italy, as well as the market fundamentals driving their future diffusion trajectories, influence the adoption of industrial heat electrification. The scenario analysis is complemented by six case studies from companies in the two sectors. The case studies, provided by a technical partner[13], present the results of a technical and economic assessment of electrification alternatives with commercially available technologies, considering current energy prices. The scenario analysis and case studies provide several insights into the factors that favour and hinder the electrification of low and medium temperature process heat.

The European Commission, in its new mandate, has placed a strong emphasis on efficiently reconciling climate and competitiveness objectives. This effort began with the Clean Industrial Deal and is expected to continue with the EU Electrification Action Plan. This work aims to inform and support policy makers in identifying objectives that drive industry decarbonisation while strengthening its competitiveness.

Chapter 2 outlines the scenario analysis conducted on the food and textile sectors, while Chapter 3 presents six case studies of companies in the two sectors. Building on insights from the previous chapters, Chapter 4 and Chapter 5 discuss the co-benefits and barriers to electrification, respectively, while Chapter 6 establishes key pillars for developing a strategic vision for action at the European level. Finally, Chapter 7 provides policy recommendations in the national context to support the electrification of heat demand in line with a decarbonization pathway by 2050.

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[12] ECCO elaboration based on Kosmadakis, Georg; 'Estimating the potential of industrial (high temperature) heat pumps for exploiting waste heat in EU industries', Applied Thermal Engineering, 20 April 2019', Applied Thermal Engineering, 25 June 2018.

[13] https://enersem.eu/

2 SCENARIO ANALYSIS

A scenario analysis was conducted on two key sectors of the Italian manufacturing industry, food (NACE 10, together with beverages NACE 11) and textiles (NACE 13), to assess the adoption of technologies for the electrification of industrial process heat of these sectors. This analysis focused on the relationship between gas and electricity prices in Italy, evaluating the competitiveness of electrification technologies based on the fundamentals of energy commodity prices. Three different energy price scenarios were hypothesised, taking into account wholesale electricity prices, including the ETS component, transmission and distribution costs, while excluding fiscal and parafiscal contributions.

The scenarios were generated using a cost-optimisation model for long-term energy planning, developed specifically for this work using the open-source software Osemosys[14]. This tool enables a computational analysis to determine the minimum cost required to meet a given energy demand (defined by type of resource, such as heat) using a set of available technologies, characterised by parameters such as investment costs and efficiency. Each technology simulates the conversion of primary energy resources into secondary ones (for example, gas boilers convert natural gas into heat), and the consumption costs of raw materials are reflected in the technology's operational costs. The model provides the cost-optimal solution (the optimal set of technologies) for the entire modelling horizon. For this analysis, the timeframe spans from 2021 to 2050. The energy consumption of the modelled sectors in 2021 was replicated based on the IDEES database[15], which provides detailed data on energy consumption and demand specific to each sector and industrial process. Over this period, new technologies may replace existing ones, representing technological innovation.

Based on ECCO's methodology of work, the scenario development was informed by a continuous exchange with relevant stakeholders, including technology providers, heat consumers, energy companies and academia, as well as the results of the case studies in terms of heat production patterns and the main characteristics of heat flows and processes.

Based on the inputs and assumptions**, four market scenarios** were developed. The model **inputs** built for this work include:

- **Projections of commodity prices:** commodity price projections serve as the main assumptions of this scenario analysis. To provide different insights, **four different projections of wholesale electricity and gas prices** were developed, covering the period from 2021 to 2050. These included ETS, transmission and distribution charges, and serve as inputs for the **four different market scenarios.**
- **Technology investment costs (CapEx):** following JRC's IDEES database, technologies currently used by the sectors were mapped for each process. The model can also select between currently available technologies or those expected to become available in the future to meet process energy demand. Price projections were defined through literature reviews and discussions with stakeholders. The initial cost of technologies is expected to decrease over time due to market adoption, especially when considering heat pumps for industrial applications. In this paper, **two policy measures on CapEx** were explored**.**

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[14] http://www.osemosys.org/

[15] IDEES database - Italian industry, 2024, JRC

- **Heat demand projections:** all scenarios were based on the heat demand of industrial processes in 2021. Demand was projected until 2050 using the growth rate of gross value added (GVA) as a driver, as indicated in the Italian National Energy and Climate Plan (NECP).[16]
- **Technological efficiency:** to reflect innovation and technological improvement, existing and newly introduced technologies were characterised by increasing efficiency, based on literature and interviews with stakeholders during dedicated meetings.

In addition, all scenarios share the following core assumptions:

- **Competitive optimisation**: the model assesses different technological options, selecting the least expensive and most efficient solution under given conditions. No constraints were imposed on maximum annual installed capacities, ensuring sensitivity to changes in commodity prices and technology investment costs. This approach was chosen because **this work does not aim to simulate industry inertia in adopting electrified solutions, but rather to determine *when* conditions become favourable for full electrification adoption.**
- **Modes of operation:** the model captures the complexity of sectoral processes by defining the specific demand each technology must meet (for example, boilers can produce steam or water >150°C, while low temperature heat pumps can only produce water <80°C). It also identifies multiple operating conditions from which the model can choose to supply the appropriate demand for each time unit (for example, in a given time unit, boilers may only produce steam if there is demand solely for steam, in the next, they may produce both steam and water >150°C if both are required, and in another, only water >150°C).
- **Weighted Average Cost of Capital (WACC):** to reflect the difficulties Italian industries face in accessing finance for non-core activities (for example, energy efficiency), the analysis assumes a WACC of 10%.

The **four market scenarios** are structured as follows:

1. **Historical price scenario:** to determine whether electrification technologies can compete based solely on expected investment costs and efficiency improvements. the first scenario assumes that commodity prices in 2050 replicate the average data from 2010 to 2020, before the energy crisis and the COVID-19 pandemic, remaining constant throughout the modelled years. Electricity and gas prices for the selected sectors were collected from the Italian regulatory authority's website and the Italian energy market platform (GME), reflecting costs for small and medium-sized companies, including transmission and distribution charges as well as ETS charges on electricity. Final prices were set at 31 €/MWh for gas and 68 €/MWh for electricity (Figure 4).

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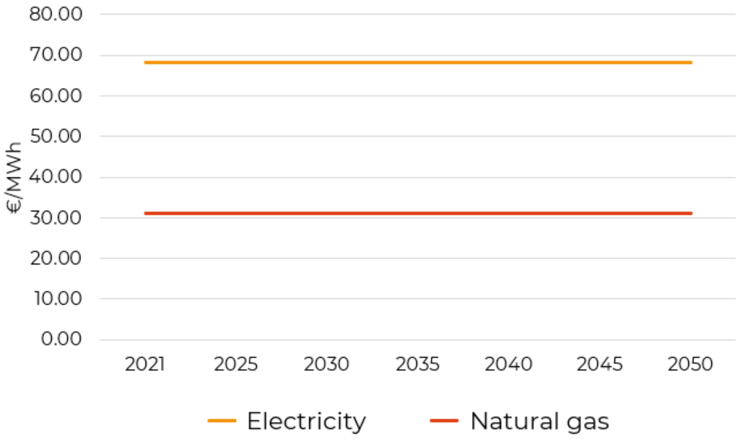
[16] PNIEC (2024), National Integrated Energy and Climate Plan, Ministry of the Environment and Energy Security.

***Figure 4 -** Electricity and natural gas prices in the 'Historic price' scenario.*



2. **Central scenario (High Gas Price):** in the central scenario, gas price projections are based on forecasts from Italy's National Energy and Climate Plan (NECP) and account for the evolution of the ETS component on electricity and the ETS2 component on gas. The latter reflects the cost of decarbonising the gas supply, which is not presently charged any additional cost. Electricity and gas prices were initially set at average values from 2010 to 2020 and then projected based on the following assumptions:
    - The price of natural gas was set at 40 €/MWh by 2050, based on the Italian NECP. Transport and distribution charges were included until 2050, considering possible national infrastructure investments[17] . A gradual increase in ETS2 prices was also assumed[18] . Given the different percentages under ETS2 for the food and textile sectors, the impact of carbon pricing differs between the two sectors.
    - The electricity price was modelled based on natural gas until 2025, after which it decreases linearly, decoupling from gas and reaching, by 2050, the levelised cost of electricity (LCOE) from a photovoltaic generation system with storage[19] . This assumes that solar energy with storage will be the main driver of electricity prices by 2050. The values were derived from the Italian NECP and DNV Energy Outlook[20]. Transmission charges for electricity were also considered, using the historical increase in tariffs from 2010 to 2020[21]. Based on these assumptions, price parity between gas and electricity is expected to be reached around 2042. Figure 5 shows the electricity and natural gas prices in the central scenario (High Gas Price).

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[17] ECCO's hypotheses based on the Italian NECP target in the Fit for 55 scenario.

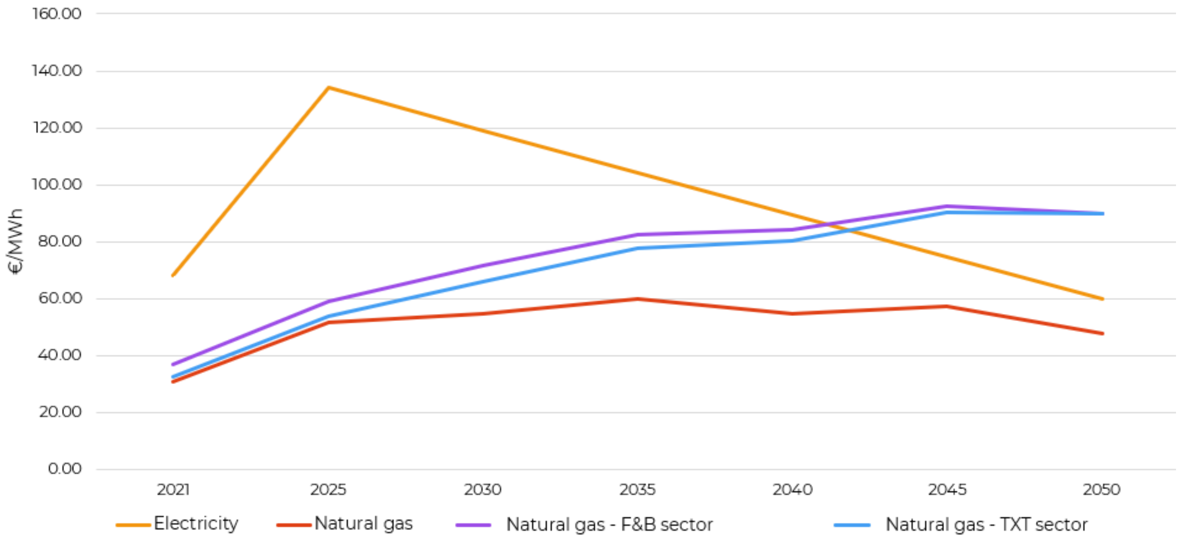
[18] ECCO on Agora databasee laboration , assuming ETS and ETS2 prices reach €210/tonneCO$_2$ by 2050.

[19] Based on the DNV energy outlook 2023 report, the LCOE of PV+storage is assumed to reach 50€/MWh by 2050.

[20] https://www.dnv.com/publications/energy-transition-outlook-2024/

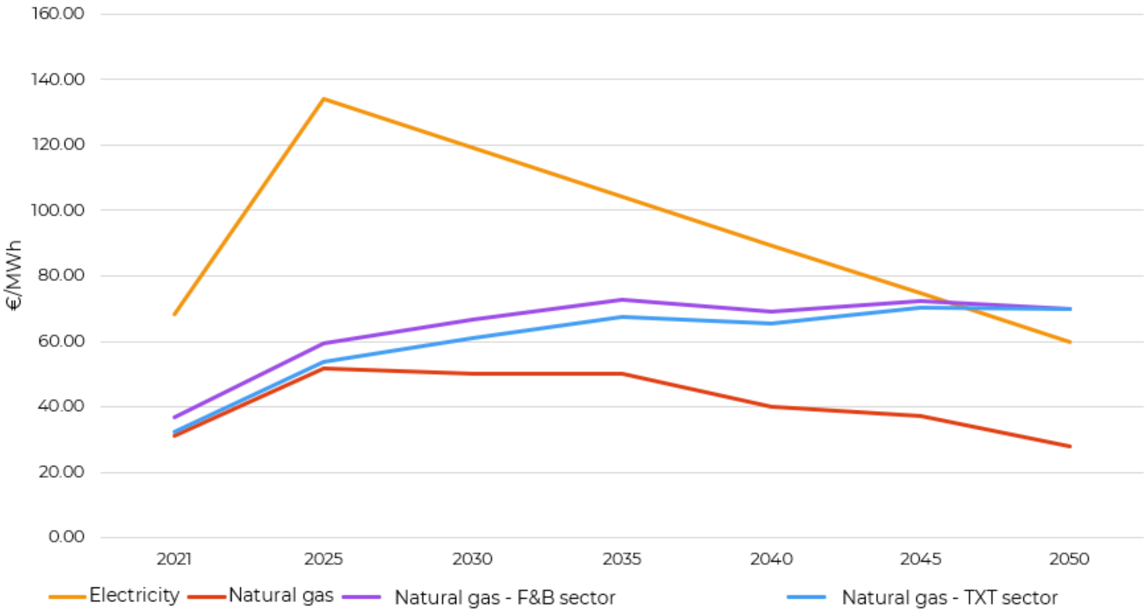
[21] Transport charges for the electricity component have been assumed considering medium-sized enterprises as the consumers.

Figure 5 - *Electricity and natural gas prices in the "High Gas Price" scenario.*



3. **Low Gas Price scenario:** given the uncertainties surrounding future natural gas price projections, a third scenario was developed that adopts a more conservative gas price forecast. This follows the same approach as the previous scenario but assumes that the natural gas price will peak at 40€/MWh in 2025 before gradually decreasing to 20€/MWh by 2050. As shown in Figure 6, the decrease in gas prices is expected to shift the convergence point between electricity and gas prices by about five years, compared to the central scenario.
4.

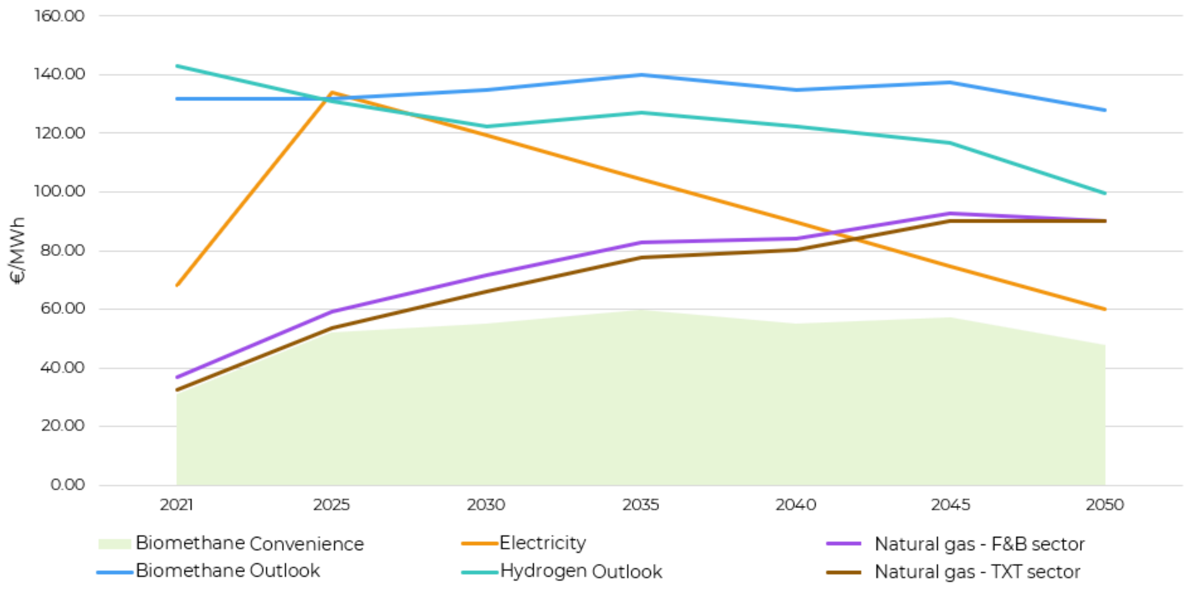
Figure 6 - *Electricity and natural gas used for the simulation of the 'Low Gas Price' scenario, based on previous gas prices assessed by the Italian energy market GME and the DNV energy outlook report.*



5. **Biomethane scenario:** this scenario explores the potential for adopting biomethane-based solutions to decarbonise the heat demand across various sectors. Current estimates suggest that biomethane prices are expected to be 2 to 3 times higher than the cost of natural gas. In

fact, projections indicate that biomethane prices could reach a wholesale cost of €120/MWh[22], including subsidies. Additional projections indicate that the cost of biomethane will likely be influenced by hydrogen prices, as hydrogen will compete for the energy supply of energy-intensive industries. Based on these estimates, it is unlikely that biomethane-based technologies will dominate the market. To facilitate their adoption, this scenario assumes that biomethane prices will be competitive with other raw materials, while gas and electricity prices remain consistent with those in the central scenario. Transport costs for both biomethane and natural gas are assumed in the same way. The green area in Figure 7 indicates the area of convenience for the biomethane price.

Figure 7 - *Biomethane price assumed in the Biomethane scenario compared to other commodity projections. The green area in the figure indicates the convenience area for biomethane price .*[23]



Since the four previous market scenario hypotheses do not account for industry inertia or potential delays in responding to preferred commodity prices for the adoption of electrification, it was deemed necessary to evaluate measures that could accelerate electrification. **Two policies were simulated** using energy price projections for the High Gas Price and Low Gas Price scenarios:

Depreciation policies: the aim of this analysis is to simulate a policy that reduces the cost of capital for new technologies and incentivises efficiency. Therefore, the weighted average cost of capital (WACC) is reduced from 10% to 4%. This measure should incentivise the model to install (i.e. invest in) new technologies to replace existing ones. In this case, all new technologies, whether gas or electricity-based, are incentivised.

CapEx subsidies for technology purchases: this analysis aims to simulate targeted policies for electrification. In addition to depreciation policies, investment costs of electrification technologies were discounted by 50% until 2040 to simulate direct electrification incentives.

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[22] Biomethane Perspectives 2024, Polimi School of Management (https://www.energystrategy.it/es-download/)

[23] This area was calculated through an iterative process described in section 2.3.4.

Table 1 summarises the list of scenarios developed in the work, their price assumptions and objectives. Table 2 summarises the policy analyses conducted for the High Gas Price and Low Gas Price scenarios.

Table 1 - *List of scenarios developed in the analysis.*

Scenario	Prices of raw materials	Objective
Historical Price	Prices replicate the wholesale average from 2010-2020, including transport and distribution charges and ETS on electricity. They remain constant throughout the scenario horizon.	Explore the adoption of electrification solely by reducing investment costs and improving the efficiency of electric alternatives.
Central (High Gas Price)	The wholesale gas price is projected according to the National Energy and Climate Plan (NECP), adding transport and distribution charges and the evolution of the ETS2 tariff. The electricity price includes transport and distribution charges and the ETS and gradually decouples from gas, reaching the levelised cost of electricity (LCOE) of a photovoltaic generation system with storage by 2050.	Explore the adoption of electrification considering the expected evolution of commodity prices, including ETS and ETS2 charges and the decoupling of electricity prices from gas.
Low Gas Price	The gas price projection includes charges as in the central scenario, but with a lower wholesale price. The electricity price is projected as in the central scenario.	Explore the diffusion of electrification as in the central scenario but considering a more conservative gas price evolution.
Biomethane	The biomethane price has been lowered compared to estimates in the literature to remain competitive with other raw materials. Gas and electricity prices are in line with the central scenario. Similar transport tariffs are assumed for biomethane and natural gas.	Explore the potential for adopting biomethane-based solutions to decarbonise heat demand across sectors.

Table 2 - *List of policy analyses conducted*

Scenario	Prices of raw materials	Objective
Depreciation	Commodity prices remain unchanged	Simulate a policy to reduce the cost of capital for new technologies and incentivise efficiency, assuming a lower WACC.
Subsidies		Simulate a combination of policies aimed at: - Reducing the cost of capital for new technologies and incentivise efficiency by assuming a lower WACC, *and* - incentivising electrification technologies by discounting their investment costs by 50%.

2.1 DESCRIPTION OF ENERGY USE IN THE FOOD AND BEVERAGE AND TEXTILE SECTORS IN ITALY

The food (NACE 10), beverage (NACE 11) and textile (NACE 13) sectors have significant potential for the direct electrification of industrial process heat, which is currently supplied primarily by the combustion of natural gas or other fossil fuels. A broad overview of the sectors analysed is provided in Table 3.

Table 3 *- Socio-economic indicators of food and beverage and textile sectors in Italy.*

Reference year 2021	**Food and Beverages (NACE 10 and 11**	**Textiles (NACE 13**
Number of enterprises[24]	53 000	11 000
% SME	99.8%	99.7%
%SME Turnover	61.8%	81.9%
Employees[24]	460 000	107 000
Profit/Export[25] **[Bn€]**	180/64	20/7.3

2.1.1 FOOD AND BEVERAGE SECTOR

In 2021, the **food and beverage sector** in Italy consumed 39 TWh of energy and generated 4.2 million tonnes of direct CO_{2eq} emissions. Of the total energy consumption, 30 TWh was used for process heat. Of the process heat consumption, 73% (21.9 TWh) was attributed to natural gas-based technologies, 32% (9.6 TWh) to electricity and the remainder to fuel oil.

The sector's energy balance was modelled by correlating specific process temperatures with the corresponding heat supply technologies. The amount of gas consumed by cogenerators was calculated using the Eurostat database[26] and assuming that all heat was produced by cogenerators. Figure 8 shows the sector's energy balance, from energy consumption to final processes.

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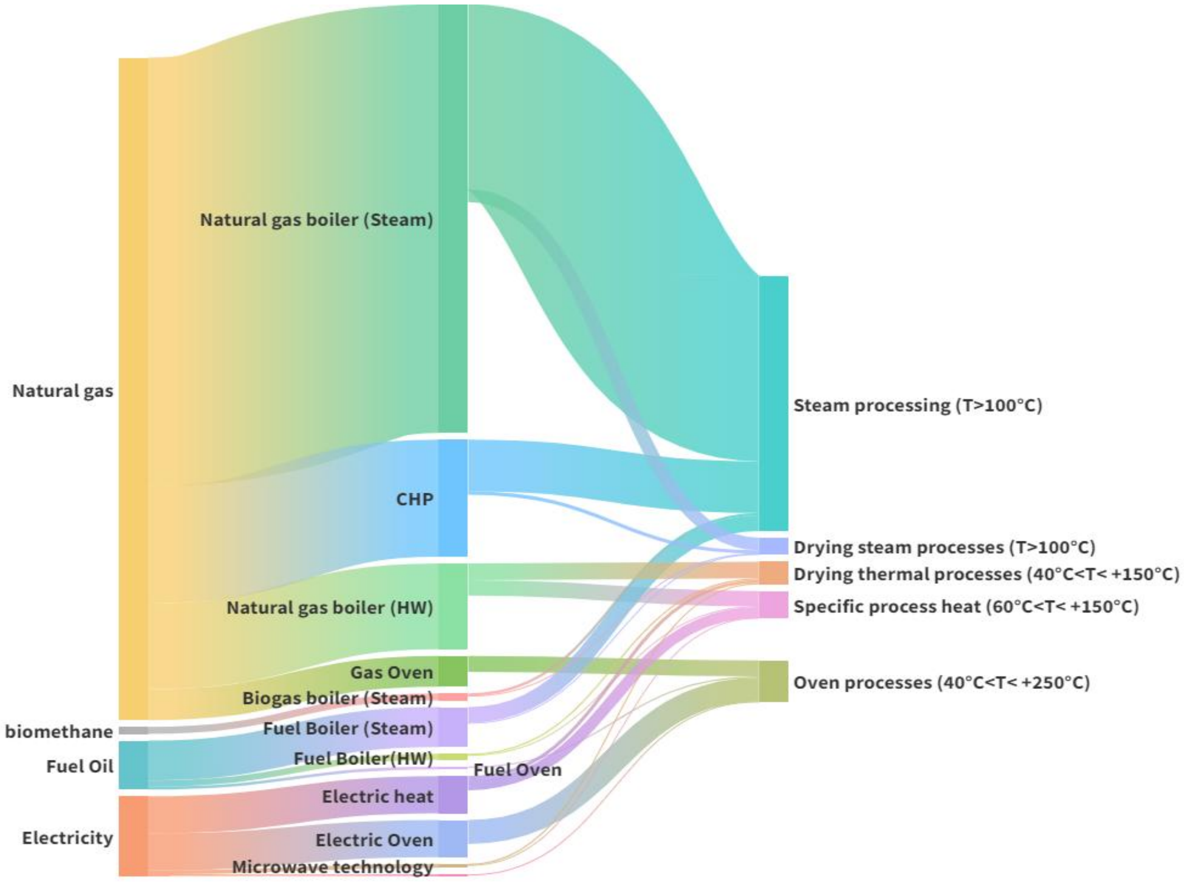
[24] ECCO elaboration on ISTAT data (2021) relative to business demography

[25] ECCO Integrated National Energy and Climate Plan: Progress Report - ECCO, 2024.

[26] Statistics | Eurostat

Figure 8 - *Sankey diagram of thermal processes in the food and beverage sector 2021, data compiled from the JRC IDEES database.*



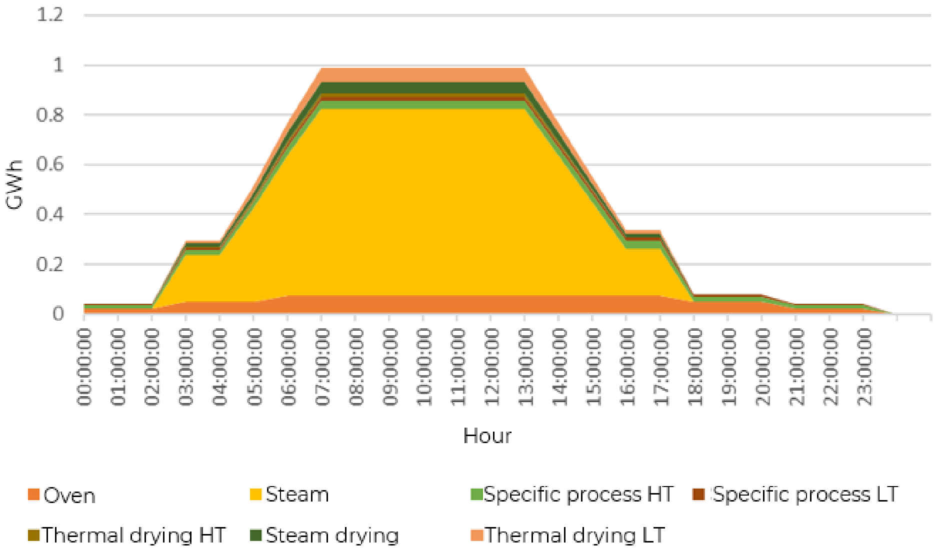
- Steam processes: In 2021, the food and beverage sector’s largest energy demand, accounting for 71%, came from steam-based processes such as pasteurisation, sterilisation, and distillation. Steam is primarily generated through the combustion of natural gas in boilers or cogeneration plants. As shown in the figure, boilers supplied 73% of the energy, while cogeneration accounted for 20%, with the remaining energy sourced from oil and biomass boilers.
- Drying processes: Drying processes represent 12% of the sector's energy consumption. These include steam drying, which operates at temperatures of up to 150°C and is mainly powered by natural gas boilers and cogeneration plants; thermal drying, which operates at lower temperatures (below 80°C) and is powered by natural gas boilers (92%) and fuel oil; and direct heat drying, which accounts for 10% of total energy demand, powered by specific technologies such as infrared or microwave systems; this sub-process is already fully electrified.
- Oven processes: Cooking processes also account for 12% of energy demand and can reach temperatures of up to 250°C. While these processes were historically powered entirely by fossil fuel-based technologies, the use of electric ovens has steadily increased, reaching 57% of the energy supply in 2021. The remaining energy is provided by natural gas ovens (38%), fuel oil ovens (7%) and microwave technologies (2%).
- Other heat-specific processes, which account for 5% of energy demand, operate at temperatures below 150°C. This energy demand profile follows the same pattern as the

cooking processes and is primarily powered by electrical appliances, with the remainder supplied by natural gas and, to a lesser extent, fuel oil.

In 2021, the overall system efficiency, considering both technological and process inefficiencies, was 47%.

The daily variation in thermal energy demand for industrial processes in the sector was assessed and incorporated into the model to identify potential peaks and determine the required capacity. The daily demand increases during the central hours of the day, peaking between 7:00 and 15:00[27] (Figure 10). This profile is assumed to remain constant throughout the year.

Figure 9 - *Heat demand profile in the food and beverage sector.*



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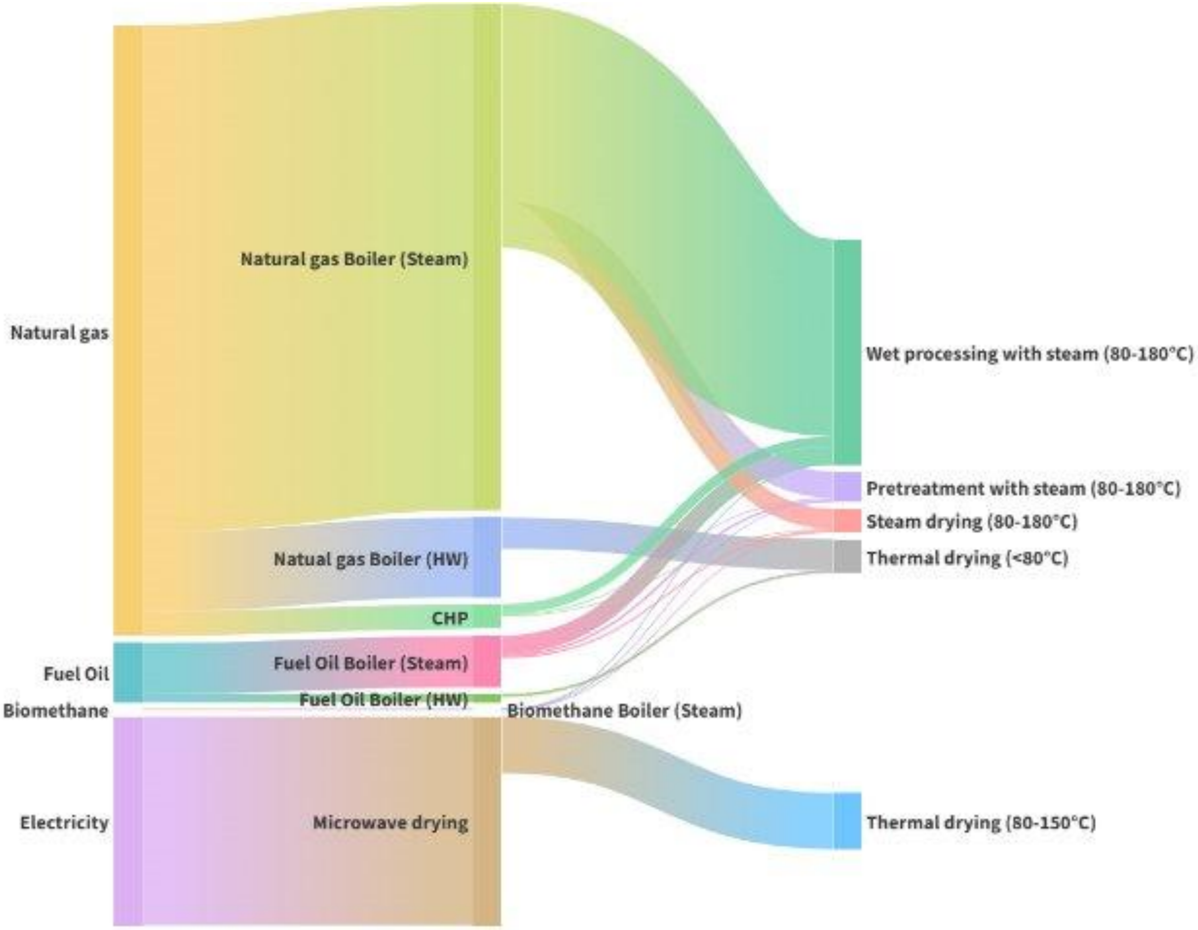
[27] The demand profiles of each process were defined based on the daily variations analysed in the case studies. As electrification of space cooling is already a viable solution within the current policy framework, the scenario analysis focused exclusively on industrial process heat in the selected sectors.

2.1.2 TEXTILE SECTOR

In 2021, final energy consumption in the **textile sector** amounted to 12 TWh[28] and generated 1.4 million tonnes of direct CO_{2eq} emissions. Of the total consumption, process heat accounted for 73% (8.5 TWh). Of the final process heat consumption, 65% was gas (5.5 TWh), 28% electricity (2.4 TWh) and 5% fuel oil. Figure 10 shows the modelled energy balance of the textile sector, calculated as previously described for the food sector.

Figure 10 - *Sankey diagram of textile thermal processes 2021, data compiled from the JRC IDEES database.*



The sector's heat demand can be classified[29] into steam processes, which account for 69% of energy demand and include pre-treatment, steam dyeing and washing processes, and steam drying. The remaining demand comes from non-steam drying processes:

- Steam processes: steam processes can reach temperatures of up to 180°C, depending on the pressure required for specific processes and materials produced; for example, dyeing synthetic fibres may require temperatures of up to 130°C, while natural fibres require 100°C. Energy demand in steam processes is mainly met by fossil fuel-based technologies, with natural gas boilers accounting for 87% of the energy share, fuel oil boilers for 8% and cogeneration for 5%.

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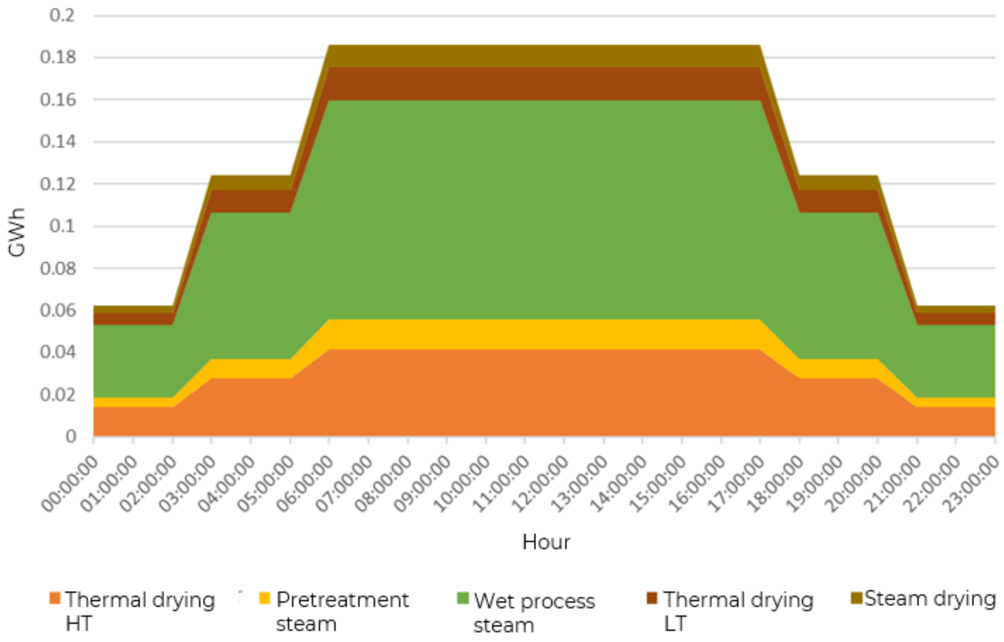
[28] Aggregated data with textiles and leather.

[29] Elaboration by ECCO on the JRC 2024 IDEES database

- Thermal drying: thermal drying, which operates at temperatures below 80°C, is mainly based on fossil fuel technologies. In contrast, direct heat drying, which is the largest contributor to energy demand among drying processes (62%), is achieved through microwave systems, making the sub-process fully electrified.

As in the food sector, it was assumed that all thermal demands of industrial processes follow the same daily variations and operate continuously, with consumption peaks between 6am and 6pm (Figure 11).

Figure 11 - *Heat demand profile in the textile sector.*



2.2 TECHNOLOGICAL OPTIONS

The initial sets of technologies in the two sectors were determined through exchanges with stakeholders and elaborations of the IDEES databases from JRC and Eurostat. In 2021, the primary technologies incorporated into the model to meet the heat demand were mainly boilers and cogenerators. Both produce steam and hot water, meeting almost all process demands. Some electric technologies are already available in 2021, such as electric and microwave ovens and infrared systems, and meet a small part of the demand. Table 4 and Table 5 show the set of technologies included in the model for both sectors, distinguishing between the initial technologies and the alternative electrification-supporting options available from 2022.

Table 4 - *Technological options in the food and beverage sector by process.*

Process	Temperature range (°C)[30]	Technologies 2021	Electrified alternatives (available from 2022)
Cooking processes	80-250	•Natural gas oven •Oil furnace •Microwave oven •Electric oven	• Microwave oven • Electric oven
Heat-specific processes	<150	•Natural gas hot water boiler •Fuel oil hot water boiler •Microwave system •Electrical system (infrared system)	• Electric boiler • High-temperature heat pump (<150°C) • Medium-high temperature heat pump (<80°C) • Microwave system • Electrical system (infrared system)
Steam processes	80-180-Steam	•Natural gas steam boiler •Fuel oil steam boiler •Biomass steam boiler •CHP (combined heat and power plant)	• Electric boiler • Heat pump with booster system (from 2025)
Drying (thermal and steam)	40-250	•Natural gas hot water/steam boiler •Hot water/fuel oil boiler •Biomass steam boiler •CHP (combined heat and power plant) •Electrical system (infrared system) • Microwave system	• Electric boiler • Heat pump with booster system (from 2025) • Electrical system (infrared system) • Microwave system

Table 5 - *Technological options in the textile sector by process.*

Process	T range (°C)	Technologies 2021	Electrified alternatives (available from 2022)
Pre-treatment with steam	80-180 steam	• Natural gas steam boiler • Fuel oil steam boiler • CHP (combined heat and power)	• Electric boiler • Heat pump with booster system
Dyeing and steam washing processes	80-180 steam	• Natural gas steam boiler • Fuel oil steam boiler • CHP (combined heat and power plant)	• Electric boiler • Heat pump with booster system (from 2025)
Drying (thermal and steam)	60-150	• Natural gas hot water/steam boiler • Hot water/fuel oil boiler • CHP (combined heat and power plant) • Electrical system (infrared system) • Microwave system	• Electric boiler • Heat pump with booster system (from 2025) • Electrical system (infrared system) • Microwave system • Low-medium heat pump. Temp. (<80°C)

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[30] IRENA (2023) Innovation landscape for smart electrification, decarbonisation of the end-user sector with renewable energy

The group of new technologies for electrification is modelled from 2022 and mainly includes heat pumps and electric boilers.

- Heat pumps are characterised by high efficiency (Coefficient of Performance, COP), compared to traditional heating technologies. Their COP ranges from 3 to 4[31] , meaning that one unit of electrical energy is converted into 3 or 4 units of thermal energy. In contrast, gas boilers achieve a maximum efficiency of 0.95. In the scenario analysis, the characteristics of these heat pumps play a key role, as they start to become competitive even when electricity prices are higher than gas prices. Most commercially available heat pumps reach temperatures of around 80°C and are included in the scenario from 2022. Those that reach higher temperature ranges (80°C < T < 150°C, referred to as 'high temperature heat pumps') are close to market application and are therefore available in the model from 2026. An additional type of heat pump, referred to as a 'booster heat pump', is also modelled. It is available from 2025 and produces steam.
- Electric boilers can provide maximum temperatures of up to 500°C and generate steam with an efficiency of up to 0.99. They are considered from 2021 as a low-efficiency electrification alternative.

The techno-economic parameters of all technologies, both initial and electric alternatives, are projected to improve until 2050 to simulate technological innovation. The following table presents the assumptions used to define the technologies in the food and beverage and textile sectors. These were collected through a literature review[32] and interviews with technology manufacturers. All scenarios incorporate the same set of technologies.

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[31] Fraunhofer ISI (2024): Direct Electrification of Industrial Process Heat. A technology assessment, potential and future prospects for the EU. Study carried out on behalf of Agora Industry.

[32] *Danish Energy Agency (2024) Technology data for industrial process heat*

Table 6 - *Techno-economic parameters of technological options*

Technology	Maximum. Efficiency achieved [%] / [COP].	CAPEX 2021 [€2023/kW].	CAPEX 2050 [€2023/kW].	OPEX (excluding energy price) [2023 €/MWh].	Operating life [years]
Oil-based technologies					
Steam boiler	97%	63.64	50.1	1.16	25
Hot water boiler	95%	50.14	42.2	1.16	25
Oven	70%	383	324	1.16	30
Natural gas-based technologies					
Steam boiler	95%	61.7	52.1	1.16	25
Hot water boiler	95%	50.1	42.2	1.16	25
Oven	70%	383	324	1.16	30
Combined heat and power plant (CHP)	50%	1567	933	10	15
Biomethane-based technologies					
Steam boiler	95%	61.7	52.1	1.16	25
Hybrid technologies based on electricity					
Microwave heating	90%	833	749	10	30
Electric heating (infrared)	96%	572	363	10	30
Electric oven	85%	550	350	10	30
Electric boiler - Hot water	99%	137	93	0.58	25
Electric steam boiler	99%	156.2	96	0.58	25
Heat pump (<80°C)	COP 4.5	833	730	0.5	20
Heat pump (<150°C)	COP4	1220	1000	0.554	20
Booster heat pump (steam)	COP2.1	1888	1080	0.579	20

It is significant to note that **mechanical vapour recompression (MVR)**[33] , was initially considered in the model of available technologies. MVR is an energy recovery system used to recycle waste heat, thereby improving the overall efficiency of the heat production system to which it is coupled. In MVR systems, waste steam from a process is recompressed at a higher pressure, increasing its temperature. This high-temperature steam can be fed back into the production process, reducing the need for additional energy inputs. These systems run on electricity and can be considered as 'boosters', as they must be coupled to a heat source, which can be provided by traditional gas boilers or electrified systems. The efficiency of MVR systems is high, and the temperatures delivered usually do not exceed 150°C. Some companies in the food and beverage industry have started to adopt these systems coupled with gas boilers, especially for concentration processes, typical of the food sector. However, these systems have not been included in the scenarios as they are generally part of solutions specific to certain processes and not generalisable. Their applicability changes depending on the local availability of waste heat, making their sector-wide penetration rate too uncertain to be assumed.

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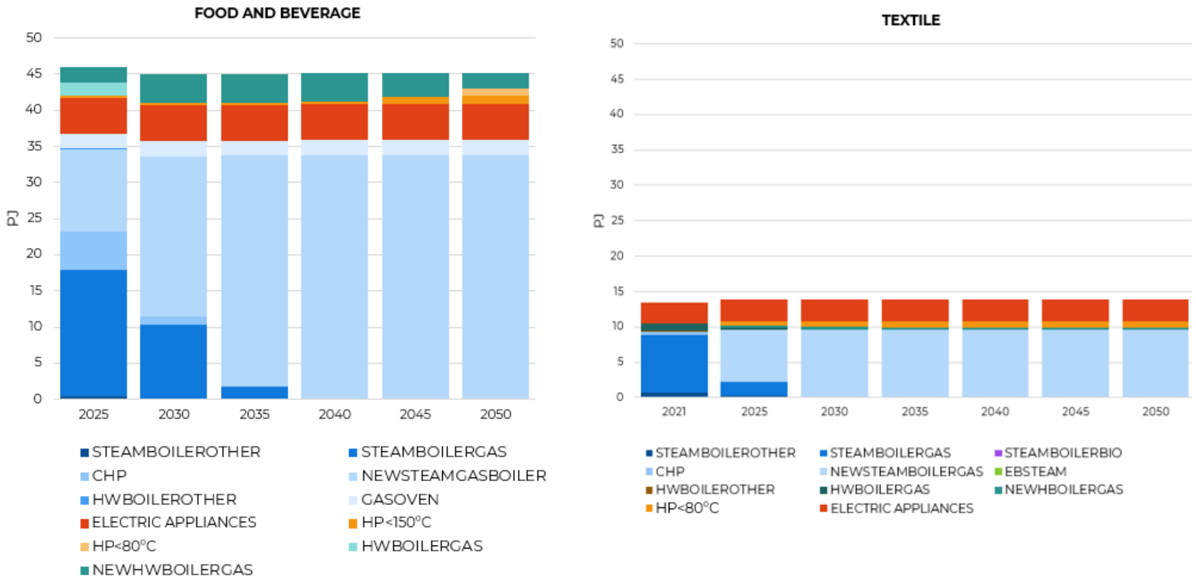
[33] *Danish Energy Agency (2024) Technology data for industrial process heat*

2.3 SCENARIOS

2.3.1 HISTORICAL PRICE SCENARIO

The scenario favours the installation of natural gas-based systems over electric options (Figure 12). Gas boilers are the most cost-effective solution in steam processes, given their low investment price, and the low price of gas prevents the adoption of more efficient electric solutions. Initial technologies are gradually being replaced with more efficient natural gas-based technologies, while cogeneration systems are being phased out at the end of their life cycle to reflect the phasing out of fossil fuels in the electricity market. The complete phase-out of oil-based technologies is achieved by 2030[34] for the food and beverage sector and in 2025 for the textile sector. Interestingly, heat pumps gain market share in processes with temperatures below 80°C, overtaking new gas hot water boilers. This is due to their high COP, which compensates for the unfavourable price of electricity compared to gas. In the food and beverage sector, high-temperature heat pumps will also be installed by 2050 to meet 30% of the specific heat demand at temperatures above 80°C. The adoption of these heat pumps occurs in the latter phase of the simulation due to their high initial investment costs. Despite the historical trend of increasing use of electric ovens in the food and beverage sector, there is no significant shift to fully electric solutions and the ratio of electric to gas ovens remains constant.

Figure 12 - *Heat production by technology in the food and beverage and textile sector - historical price scenario*



The adoption of low-temperature heat pumps increases the electrification rate of thermal processes in the sector. In food and beverage processes, the electrification rate increases slightly from 11% in 2021 to 15.6% in 2050. In textile processes, which have a higher initial electrification rate of 21%, it reaches 28.9%. In this scenario, decarbonisation of the sectors is not achieved. However, given the efficiency gains over the years in all technological options, including gas boilers, direct emissions in 2050 are reduced by about 50% in both sectors compared to 2021 (Figure 13, right), reaching less than $3MtCO_2$[35]. The role of electric technologies in reducing emission amounts to $1.7MtCO_2$, while the rest

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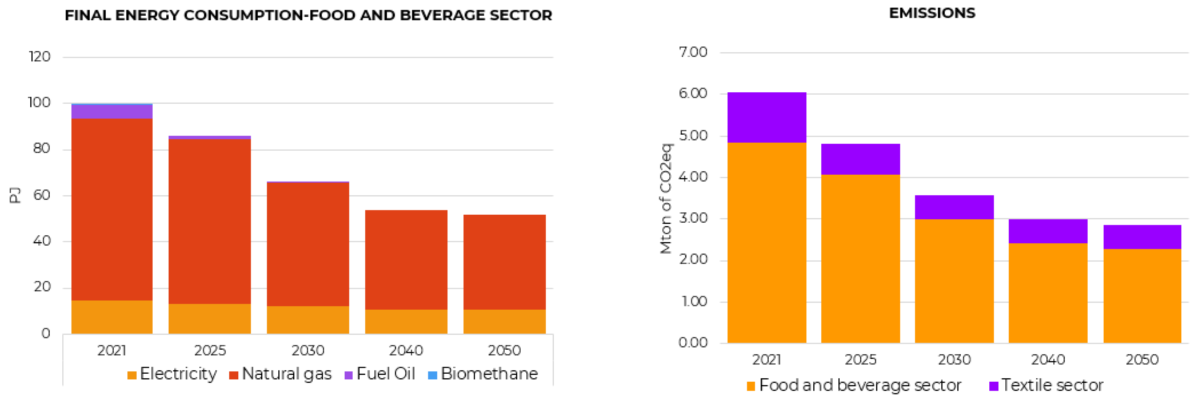
[34] The production of electricity from cogeneration has been excluded by hypothesis, as it is not compatible with a trajectory of a net zero electricity system.

[35] Indirect emissions from the electricity system are estimated to decrease from 1 Mton CO_2/a in 2025 to 0 Mton CO_2/a in 2050, according to assumptions based on the 2050 energy mix of the Italian NECP.

is achieved through the efficiency of new gas boilers, which will replace all existing boilers as early as 2040. This is visible in the final energy consumption pathway (Figure 13, left), where gas consumption in 2050 is almost 50% lower than in 2021. The contribution of heat pumps amounts to 0.8 billion Scm saved (30 PJ).

Figure 13 - *Left) Final energy consumption in the food and beverage sector. Right) Direct emissions 2021-2050 in the food and beverage and textile sectors - Historical price scenario.*

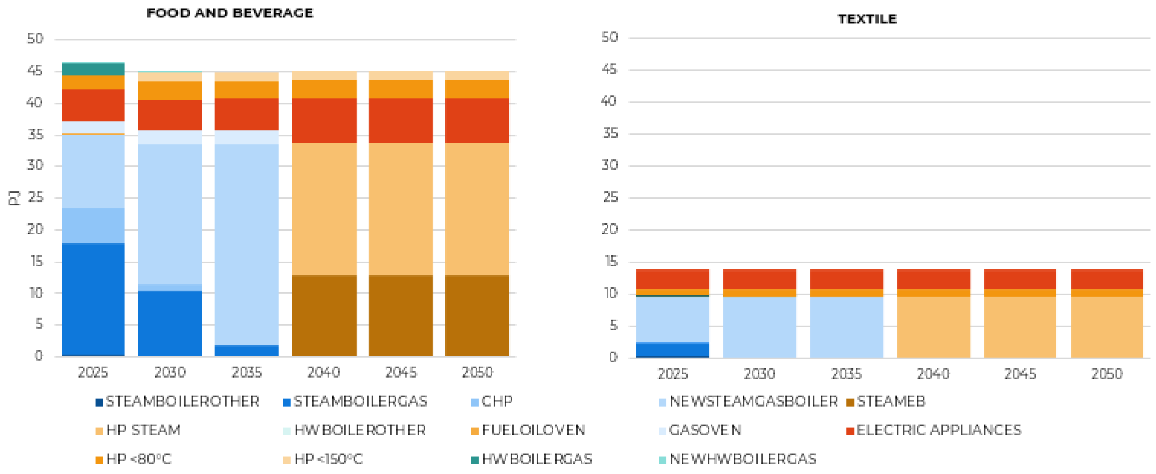


This significant gas reduction is mainly due to the low system efficiency in 2021 (47%): this value is lower than that of existing gas boilers but reflects the actual consumption of the sector and the energy mix of the JRC's IDEES database.

2.3.2 HIGH GAS PRICE (CENTRAL SCENARIO)

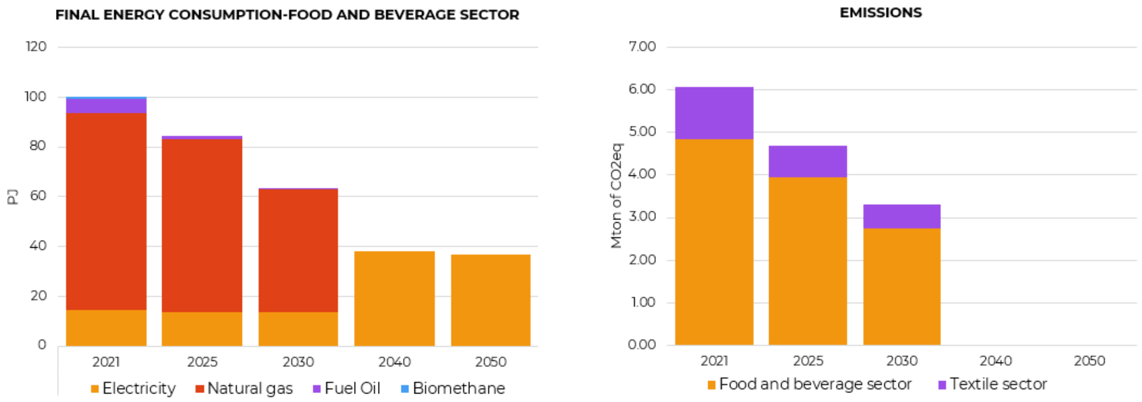
In this scenario, the price of electricity is set to be lower than that of natural gas by 2042. However, the scenario shows that full electrification is achieved by 2040. This means that electrification is achieved when the ratio of electricity to natural gas (including ETS costs) is 1.1.

Figure 14 - *Heat production by technology in the food and beverage and textile sector - High Gas Price*



In processes with temperatures <80°C, heat pumps replace gas boilers by 2025. For steam processes, from 2025 to 2035, the model adopts new steam gas boilers, which are subsequently replaced by electric alternatives. By 2040, heat pump systems with boosters meet the total steam demand in the textile sector, while in the food and beverage sector they cover most of it, in parallel with electric boilers. These technologies are still used in the technology mix, despite their lower efficiency, due to the high capacities required in the sector. In fact, the exclusive adoption of heat pumps with boosters would result in a significant increase in system costs. Figure 15 shows the final energy consumption and direct CO_2 emissions in this scenario. Decarbonisation of both sectors is achieved by 2040. The reduction in emissions from 2021-2030 is due to the replacement of gas boilers with new, more efficient gas boilers, and from 2030 onwards, the full adoption of electric technologies.

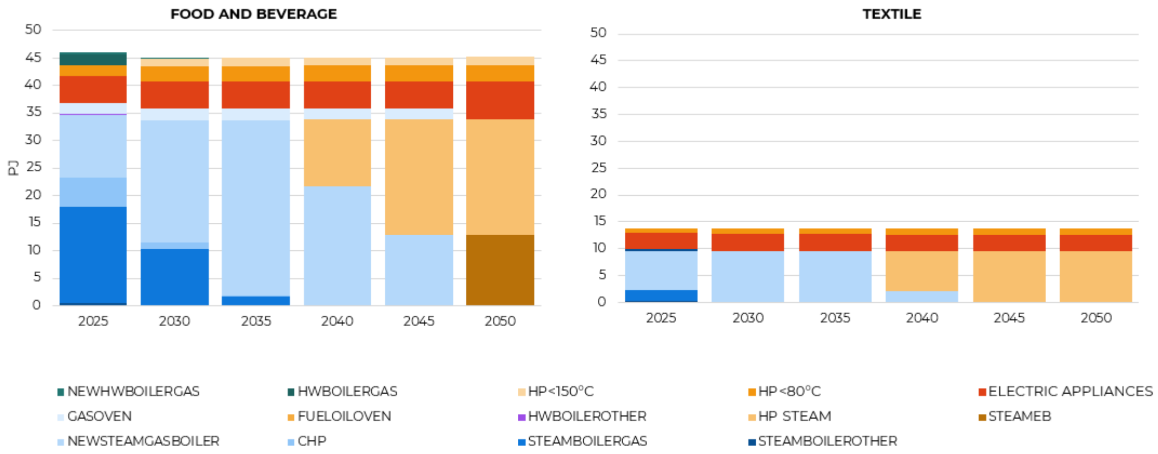
Figure 15 - *Left) Final energy consumption in the food and beverages sector. Right) Direct emissions 2021-2050 in the food and beverage and textile sectors - High Gas Price scenario*



2.3.3 LOW GAS PRICE SCENARIO

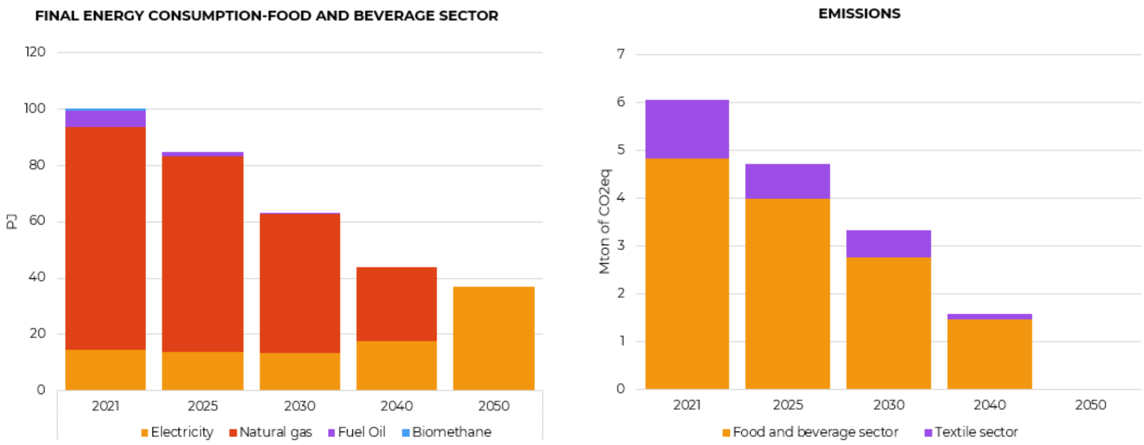
In this scenario, price parity between electricity and gas is reached in 2048 and 2044, respectively, in the food and beverage and textile sectors, due to the assumed lower gas price. Therefore, full electrification is expected by 2050. Heat pumps are still identified as the most cost-effective technology in processes <80°C by 2025, as in the previous scenario, while steam processes are electrified only after 2045. Full electrification is achieved by installing heat pumps with boosters and, in the case of the food and beverage sector, also electric boilers.

Figure 16 - *Heat production by technology in the food and textile sector - Low Gas Price scenario.*



Decarbonisation of the two sectors is to be achieved by 2050 (Figure 17).

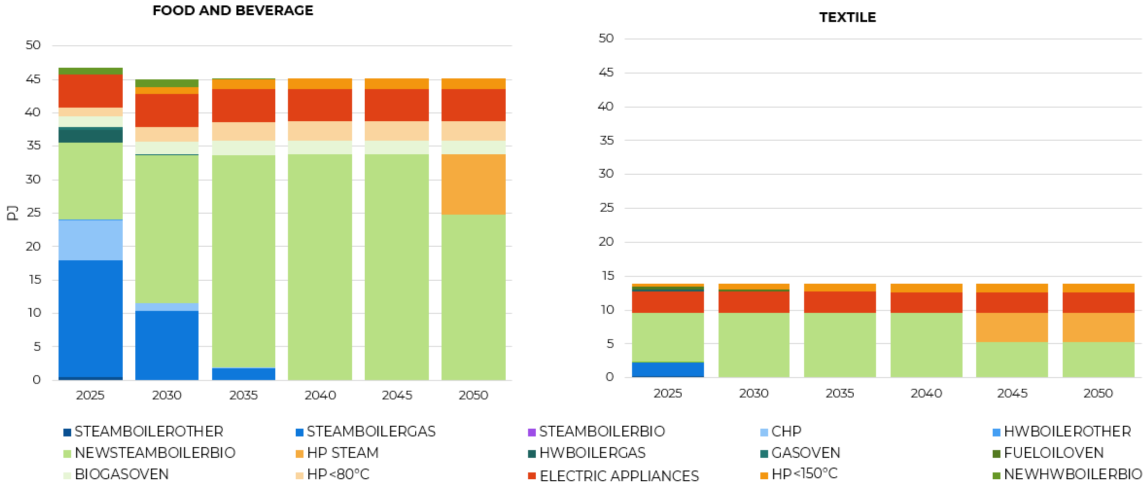
Figure 17 - *Left) Final energy consumption in the food and beverage sector. Right) Direct emissions 2021-2050 in the food and beverage and textile sectors - Low gas scenario price.*



2.3.4 BIOMETHANE SCENARIO

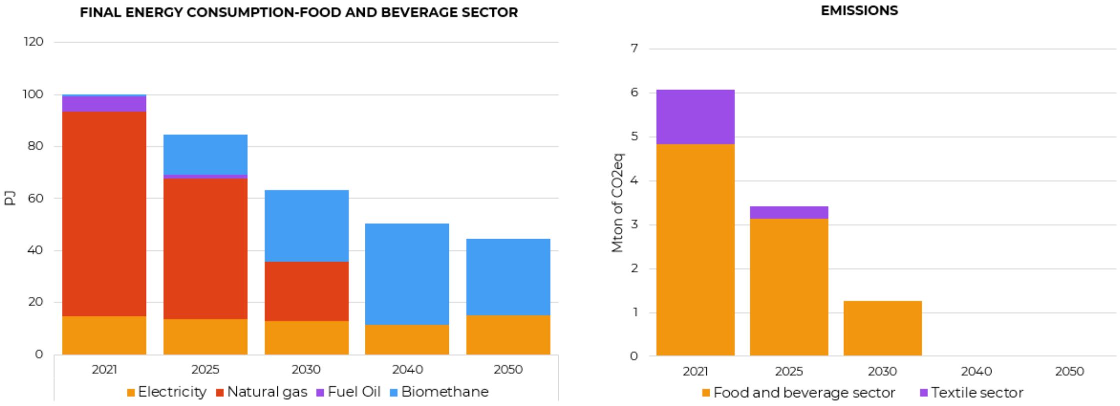
In this scenario, efficient biomethane boilers surpass the installation of gas boilers. Interestingly, even in this scenario, heat pumps replace existing technologies in processes with temperatures below 80°C (Figure 18). Due to the decrease in electricity prices, heat pumps with booster systems also appear in the mix between 2045 and 2050.

Figure 18 - *Heat production by technology in the food and textile sector - Biomethane scenario.*



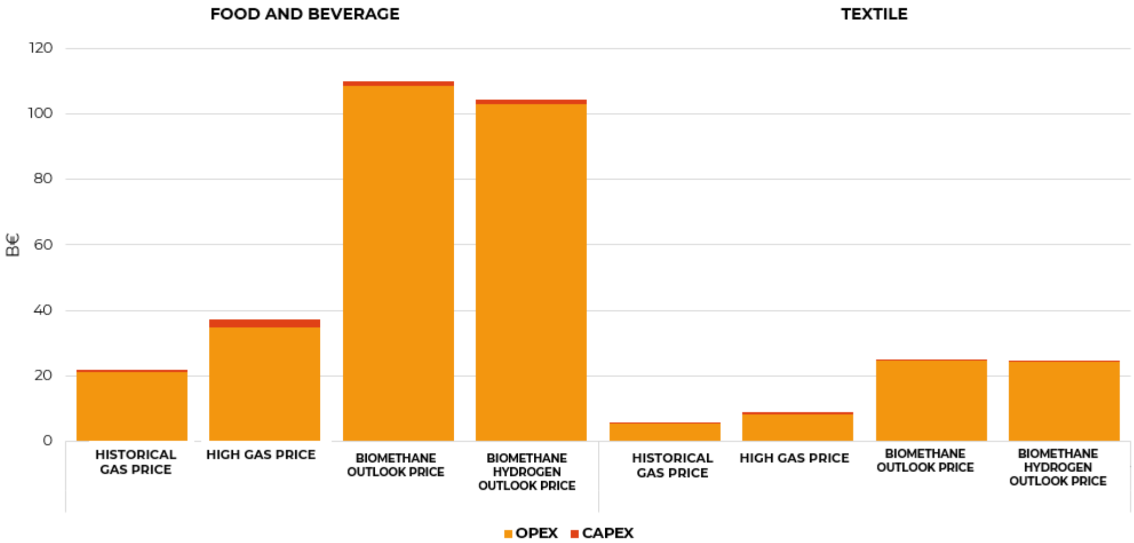
Replacing the technology mix with biomethane and electricity-based technologies allows for a reduction in direct emissions by 2040 (Figure 19). The rate of replacement of existing technologies with new biomethane-based technologies is faster in the textile sector, enabling the complete decarbonisation of direct emissions by 2030.

Figure 19 - Left) Final energy consumption in the food and beverage sector. Right) Direct emissions 2021-2050 in the food and beverage and textile sectors - Biomethane scenario



As mentioned in Chapter 2, this scenario assumed a biomethane price lower than that of gas. This was done to force the adoption of biomethane solutions to decarbonise the sector's process. However, price estimates reported in the literature suggest that the price of biomethane will be higher. Therefore, a system cost analysis based on literature prices is shown in Figure 20. In the analysis, operational (opex) and investment (capex) costs are compared across various scenarios; for the biomethane scenario, raw material costs were considered both relative to literature prices (biomethane outlook price) and assuming alignment of the biomethane price with that of hydrogen (biomethane hydrogen outlook price).

Figure 20 - *Cumulative capital and operational costs of the simulation (2021-2050) for the food and textile sector, considering biomethane price estimates.*



As a result, the costs of the biomethane scenario are significantly higher compared to other scenarios, failing to compete with gas and electric solutions. Moreover, other factors prevent biomethane from being a solution for decarbonisation, at least in these sectors. The availability of the raw materials needed to produce biomethane may not be sufficient. Despite Italy being one of the European countries with the highest potential for biomethane production, with national and European estimates predicting a production of 5.8 bcm by 2030 and 14.5 bcm by 2050[36] , production could be lower than the estimated yield. In 2023, despite national incentives for the production of 1 bcm of biomethane, only 35% of this potential was realised.

2.3.5 POLICY ANALYSIS

Figure 21 illustrates the different technological mixes when considering depreciation policies and subsidies for technology purchases, assuming the commodity price projections of the High Gas Price scenario. Similar results are obtained using the commodity price projections of the Low Gas Price scenario. The first effect is the complete shift from electric boilers to heat pumps with boosters for steam production.

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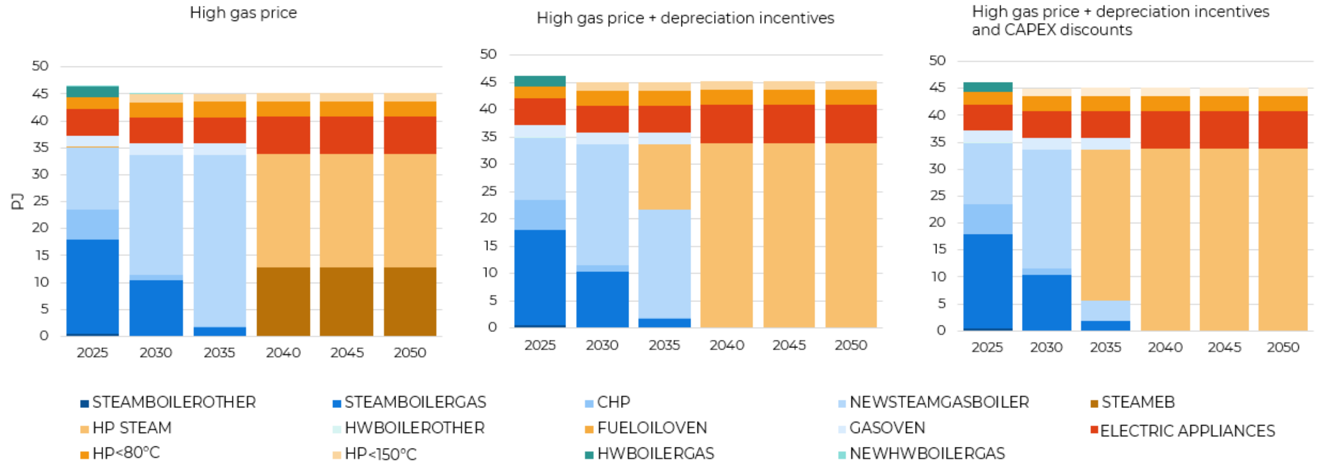
[36] European Biogas Association, 2024, Biogas towards 2040 and beyond.

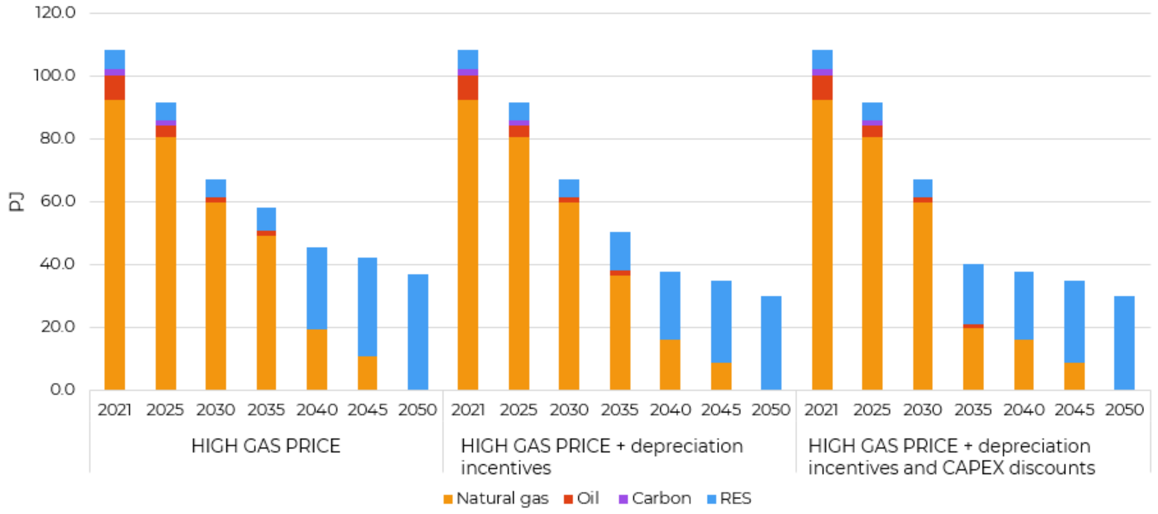
Figure 21 - Heat production by technology in the food and beverage sector - High Gas Price scenario (similar results defined in the textile sector) Left) results of initial scenario using weighted average cost of capital (WACC) at 10%; centre) results of scenario using WACC at 4%; right) results of scenario using WACC at 4% and CapEx cost discount of energy-efficient electrification technologies.



Although full electrification is achieved by 2040, policies allow the introduction of electrification in steam processes five years earlier, reaching 86% as early as 2035. The same trends are observed in the textile sector. Furthermore, the results show a prioritisation of more efficient technologies, predominantly heat pump-based solutions, which now outperform electric boilers, resulting in significant improvements in the overall energy efficiency of both sectors. Low-temperature heat pumps remain the most cost-effective option in non-steam processes <80%, and their adoption follow a similar pattern to market scenarios.

The adoption of highly efficient electric technologies is in line with the **'Energy Efficiency First' principle**. The highest primary energy consumption occurs in the High Gas Price scenario, linked to the use of electric boiler technologies in the absence of support policies. In this case, energy consumption is 20% higher than in the other two scenarios, where heat pump systems with boosters show higher penetration rates. This difference is evident in the 2035-2050 period.

***Figure 22 -** Primary energy consumption in the food and beverage sector - according to the three simulated scenario variants*



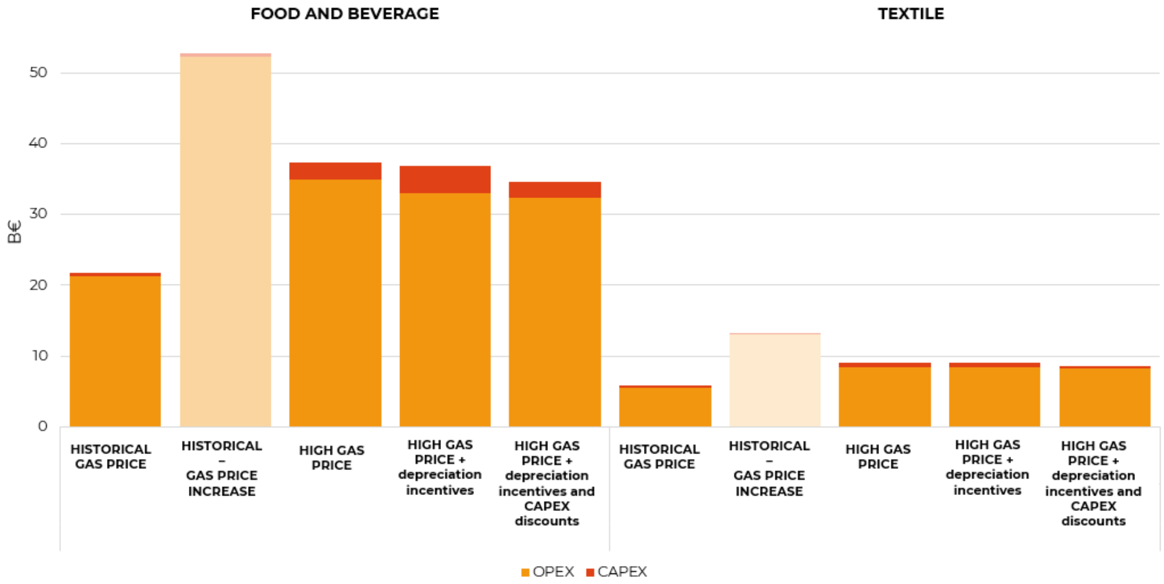
2.3.6 EVIDENCE FROM THE STUDY

The results of the scenario analysis produce some general evidence:

1. Considering wholesale electricity and gas prices, as well as transmission and distribution costs, electrification of processes below 80°C appears to be a cost-effective solution as early as 2025, without the need for supporting policies. However, this electrifiable demand is limited to about 10% of thermal uses, excluding space heating. At the same time, the relatively high efficiency of electric technologies for processes above 80°C does not compensate for their capital costs, hindering their adoption. Therefore, with current electricity and gas prices and without supportive policies, full electrification of the sector and decarbonisation are not achieved.
2. All processes are fully electrified after the gradual decoupling of electricity prices from gas towards the cost of production from renewable sources (e.g. a photovoltaic plant with storage). Other factors supporting electrification include the ETS2 contribution, which affects gas prices, and the gradual reduction in the investment costs of electric technologies. According to the analysis, this condition is achieved by 2040 in the High Gas Price scenario and 2045 in the Low Gas Price scenario. However, the technological mix is not optimal from an energy efficiency perspective, as the replacement of gas-based alternatives with electric ones is driven only by the electricity-gas price ratio, which is considered cost-effective when this ratio reaches 1.1, according to the model assumptions.
3. When policies for electrification are included through financial mechanisms and capital cost incentives, efficient heat pumps are adopted five years earlier. These measures contribute to reaching an electrification rate of 86% by 2035 in the High Gas Price scenario for the food and textile sectors. Even in the Low Gas Price scenario, the adoption of heat pumps is anticipated, with the electrification rate reaching 92% and 100% by 2040 for the food and textile sectors, respectively. Policies lead to long-term cost savings, as shown in Figure 23. According to the analysis, the cost of these policies amounts to 2.3 billion euros for the state from 2025-2040 in the High Gas Price scenario and 2 billion euros in the Low Gas Price scenario, considering both the food and textile sectors. Supporting policies are crucial to address the high cost of electric technologies and accelerate their market adoption, speeding up decarbonisation of low-temperature heat in industry.
4. Biomethane is not expected to compete with electrification as a decarbonisation solution for the food and beverage and textile sectors, as its price estimates are not competitive with gas and electricity. Additional concerns relate to the availability of the feedstock required to meet the future demand for biomethane expected from the entire Italian industry, including sectors with high energy consumption.

Finally, a consideration emerges on the technological lock-in of gas-based solutions and its cost for industries. In the event that the path to electrification is not started and the technology mix remains mainly gas-based (as in the Historical Gas Price scenario), when the gas price is increased by the ETS2 contribution, as assumed in the central scenario, operating costs are bound to increase significantly and the electrification scenarios are still the most cost-effective, as shown in Figure 23.

Figure 23 - *Cumulative operational and capital costs of the simulation (2021-2050) for the food and beverage and textile sectors.*



3 CASE STUDIES

Six case studies were analysed to assess possible barriers to electrification with technologies already available on the market. The cases were provided by a technical partner and supplemented with information gathered through meetings with stakeholders and questionnaires sent to Italian companies in the selected sectors.

In all case studies, commodity prices for 2023 were considered: 0.5€/m3 for natural gas, 0.25€/kWh for electricity and 73€/tonne CO_2 for ETS allowances. In contrast to the scenario analysis, these prices include tax and parafiscal contributions, such as general system charges, excise duties and VAT.

Each case study was built following a structured checklist to define the electrification potential (see ANNEX I: Case Study Checklist).

For the **food and beverage industry**, four different case studies were conducted, covering three dairy industries and one brewery.

The first dairy factory produces around 100,000 wheels of Grana Padano DOP per year and processes about 47.5 million litres of milk. Approximately half of the company's heat requirements are in the cooking phase, which currently requires low-pressure steam at around 55°C. The remaining heat is used for less energy-intensive processes requiring hot water at temperatures between 80°C and 85°C. The plant's thermal power plant consists of two steam boilers with a capacity of 2 MW each. The study proposed replacing the current steam boilers with two 200 kW heat pumps that use the condensate from the chillers as a heat source to provide heat at 85°C, and an electric boiler of 250 kW to generate steam.

The second dairy factory considered is a small to medium-sized enterprise that produces Lombardy DOP cheeses (Taleggio, Quartirolo) and butter, processing around 35 million litres of milk per year. The plant's main heat demand is met by a natural gas boiler providing approximately 4.2 GWh per year.

The use of steam in this dairy factory is almost completely avoidable and can be replaced with water at a temperature of 85°C. The only current non-substitutable use is the direct injection of steam into multipurpose systems for the production of Quartirolo DOP cheese, which takes place on a limited number of days per week. It is proposed that the demand for this specific steam-based process is met with an electric steam boiler (1 MW). The remaining heat demand (80% of the annual demand) can be met with a 1 MW heat pump.

The third case study concerns **an industrial dairy factory** producing 50,000 tonnes of soft cheese and stretched cheeses per year. The plant's heat demand is currently met by three natural gas boilers and two combined heat and power (CHP) plants, which supply approximately 50 GWh of thermal energy per year. The following technological mix was considered for the electrification of this plant:

- 1 550 kW heat pump (60°C) powered by recovered heat from the return of chilled water (8-19°C);
- 1 x 2.5 MW heat pump (80-90°C) powered by heat from refrigerant condensation (available at 30°C);
- 1 4 MW heat pump (70°C) powered by external air;

- 1 MW electric boiler to meet the remaining high-temperature heat demand (superheated water or steam).

In all analysed cases of dairy factories**,** the overall energy demand is evenly distributed throughout the year, with no significant seasonal variations. However, on a daily basis, most heat-intensive processes (cooking, pasteurisation, sterilisation) are concentrated in the morning hours, **peaking between 6:00 and 14:00.**

For the beverage industry, the case study considered a medium-sized **industrial brewery** producing 1,000,000 hl/year. Heat inputs at different temperatures, from low to medium, are required during production. The most heat-intensive processes are malt boiling, which reaches temperatures of 108°C, and bottle pasteurisation, which reaches 70°C. Currently, heat is supplied by natural gas boilers that generate 20 GWh per year.

In this case study, 50% of the thermal energy needs could be met with heat pumps, powered by waste heat from the brewing process and refrigerators.

Regarding steam supply, two alternative solutions were evaluated, one based on electric boilers and one with biomethane boilers, as the plant produces 20 tonnes of waste (threshing) per year that could be used to produce biogas through anaerobic digestion.

In the **textile sector**, two case studies were assessed. Both involve industrial wool mills producing approximately 2,500 tonnes of fabric per year. In these cases, thermal energy is generated with gas boilers which produce steam at 9 bar and 175°C. The annual heat demand for the industries is 11.25 GWh in the first case study and 19.8 GWh in the second. The plant operates consistently throughout the year, with daily fluctuations. The majority of energy consumption occurs between 6:00 and 18:00.

The plant in the **first case study** only performs fabric dyeing processes, with temperatures ranging from 70 to 120°C. The dyeing process requires precisely controlled thermal ramps, achieved by heating water with steam. The water used in the process is extracted at around 35-40°C, treated to filter and remove chemicals, and then disposed of.

The proposed solution involves installing a 460 kW heat pump that recycles heat from wastewater generated by the dyeing process. The recovered heat is used to pre-heat the tank from which the dyeing machines draw water, increasing the tank temperature from 35°C to 50°C, thus reducing the thermal load required for steam generation. An electric boiler has been included for steam generation.

The plant analysed in the **second case study** has an integrated production process, including washing, drying and finishing processes. The proposed intervention involves using infrared heating systems, which account for 8% of the heat demand, heat pumps to meet low temperature demands (<65°C) using waste heat flows from dyeing processes, and electric boilers for steam production. A final part of the heat load demand (3%), which requires an open flame (singeing process) to create a smoother and more uniform surface on the fabric, is not considered electrifiable and no alternatives were considered.

3.1 CASE STUDY RESULTS

Tables with the detailed results of each case study can be found in Annex II of this report. The analysis shows that electrification of medium and low-temperature process heat is technically feasible for almost all the evaluated heat streams. However, the cost of electricity remains a major barrier to the adoption of electrified solutions over gas-based ones.

In all cases, full electrification is not economically viable under current natural gas and electricity prices, as outlined in the previous section, when accounting for fiscal and parafiscal charges. When comparing energy costs per kWh, electricity is five times more expensive than gas. This means that to be cost-effective, the electric solution must have a COP of 4.5 or higher (considering an efficiency of 0.9 for natural gas generators).

The case studies demonstrate that COP is highly dependent on the operating conditions of the heat pump, the temperature of the cold source and the supply temperature of the system. However, for low temperatures (<80°C), there is a relatively wide price range where electrification becomes cost-effective. It is therefore possible to identify the price ratio between electricity and natural gas below which electrification is cost-effective (spark index): for low temperatures, the index is approximately 3.16, when replacing a gas boiler with a heat pump[37], while at higher temperatures, it drops to 1.04, when considering the use of an electric boiler.

Technically, steam production can always be electrified with electric boilers, but their lower efficiency compared to heat pumps leads to higher OpEx than gas-based solutions due to higher electricity prices. Therefore, the design of electricity-based alternatives for steam production must maximise efficiency by implementing customised heat recovery solutions (whey cooling, recovery of compressed air, use of condensation heat from chillers) at low temperatures. The availability of waste heat, even below 50 °C, is a decisive factor in steam generation, which is required in 2 out of 4 cases using heat pumps: in the production of Grana Padano cheese, for its use in double cooking grounds, and in the production of beer, for the cooking of wort. In both cases, very low pressure steam is required, compatible with heat pumps for the production of superheated water and the subsequent evaporation and mechanical vapour compression. In the case of Grana Padano production, waste heat is not available to generate steam with standard heat pumps, except inefficiently with a series heat pump system (double jump).

The contribution of the EU ETS price can also be assessed. Full electrification which allows emissions to fall below regulatory thresholds eliminates this cost component. However, cost-effectiveness changes on a case-by-case basis. An example is the industrial dairy factory. Since it is subject to ETS, electrification would reduce the costs associated with purchasing CO_2 allowances. The plant's emissions were estimated based on thermal energy demand, assuming a 95% average heat generation efficiency and a natural gas emission factor of 1.991 kg CO_2/Smc. More than 11 thousand tonnes of CO_2 are generated each year. The price of CO_2 is variable and generally increasing. Estimates for the next four years see the price of ETS allowances at around 85 euro/tonne CO_2, with further increases expected over the following four years. Therefore, the savings on allowances amount to around €950,000 per year, making the electricity option more favourable, but still not fully competitive compared to the baseline.

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[37] These values assume a COP of 3 for the heat pump, and gas and electric boiler efficiencies of 0.95 and 0.99 respectively.

Finally, the case study on the industrial dairy factory shows how natural gas-powered cogenerators can create a strong technological lock-in. Incentives to support high efficiency cogenerators are in fact included in current national incentive schemes (see Annex III).

In conclusion, the case analysed studies reveal that under current natural gas and electricity prices, including fiscal and parafiscal contributions (such as general system charges, excise duties and VAT), the economic prospects for industrial heat electrification are negative, particularly for businesses with steam-based processes, despite technical feasibility.

This hinders the development of a concrete pathway towards phasing out natural gas in the industrial sector.

4 DISCUSSION ON THE CO-BENEFITS OF ELECTRIFICATION

Energy security and industrial competitiveness

The REPowerEU strategy, initiated in response to Russia’s invasion of Ukraine, has underlined the importance of energy security in Europe. Industrial electrification can be an important step towards energy security in countries like Italy that are still heavily dependent on fossil fuel imports. As of 2022, only 5% of the natural gas consumed in Italy was produced domestically[38] . Electrifying the industrial sector can reduce this dependency, limiting exposure to price and supply fluctuations associated with the risks linked to the instrumentalisation of energy as a tool for political and geopolitical pressure.

Since 2022, Italy has sought to reduce its vulnerability by diversifying gas supplies and investing in renewable energy. This strategy does not eliminate the risks of instrumentalisation of the energy supply, but offers some ways to mitigate them. However, geopolitical tensions may still influence planned investments in new gas infrastructure.

New supplies from North Africa are subject to political instability, while suppliers such as Azerbaijan and Qatar have long-term contracts that conflict with EU decarbonisation targets[39] . In addition, LNG shipments from Qatar face security risks along key maritime routes, and potential price increases in US supplies add further uncertainty. These factors contribute to the risks related to price volatility of natural gas supplies, which surged sixfold following Russia‘s aggression compared to 2018 levels[40] , subsequently driving up electricity prices.

Expanding renewable energy production, as simulated in our scenarios, will help decouple electricity prices from gas prices, reducing the risks related to price volatility and strengthening Italy's industrial competitiveness.

Furthermore, Europe remains competitive in the industrial electrification technology sector, both in production and technology development, as highlighted in the Draghi report[41] ,[42] . While the renewable energy sector is characterised by a strong Chinese dominance in terms of production capacity, the industry for electrification enabling technologies can be a major strength for Europe, particularly given its early competitive positioning in this field.

Improving grid flexibility and demand response

The electrification of heat in industrial processes could also provide benefits to the electricity system through the development of flexibility options, the integration of renewable energy and the improvement of grid stability.

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[38] Natural gas budget, Ministry of the Environment and Energy Security

[39] Yassir, N. 'How Egypt's crackdown on Gaza protests shows the fragility of the Sisi regime'. The New Arab, 5 December 2023,

[40] Electricity Market. "Electricity Market Outcomes. *Electricity Market*. Accessed December 2024,

[41] E3G. *An action plan for electrification to secure the future of European industry.* E3G, 2024

[42] European Commission. (2024). *The future of European competitiveness: In-depth analysis and recommendations*. European

The adoption of demand response solutions, such as battery or electro-thermal energy storage (ETES)[43] could enable industries to decouple their load from the grid, with a twofold benefit of supporting grid balancing and decoupling electricity prices from gas.

Demand response mechanisms can support grids in balancing the intermittency of electricity production from renewable energy sources, shifting industry load demand throughout the day or allowing for the temporary interruption of electricity supply during peak demand. These interventions can take place without compromising the industry's energy security, even when it is not possible to shift the load due to the specific nature of production processes, which require products to be subjected to multiple stages with precise durations and defined heating temperatures.

In the two sectors analysed in this work, load analysis revealed that energy demand, particularly for steam-intensive processes, peaks in the middle hours of the day. However, this may vary depending on production patterns and energy requirements in terms of quantity and timing. Therefore, the key element for the development of flexibility options is to ensure wide access to voluntary flexibility for market participants.

In this way, the grid should no longer rely on the availability of gas-powered plants, allowing electricity prices to decouple from gas and reflect cheaper renewable energy production. This decoupling could also drive further developments in the electricity market, for example by accelerating the adoption of new products for long-term price contracts, such as power purchase agreements (PPAs) 24/7 .[44]

Local pollution and health benefits

Finally, electrification of process heat could bring significant benefits to human health by reducing harmful emissions. In addition to CO_2 emissions, fossil gas combustion results in the emission of nitrogen oxides (NOx), carbon monoxide (CO), nitrous oxide (N2O), volatile organic compounds (VOC) and methane (CH4).

In addition to primary pollutants, which result from direct emissions from natural gas combustion, it is necessary to carefully assess the generation of secondary pollutants, which have the most harmful consequences for human health. In the case of natural gas, these pollutants include PM2.5 and tropospheric ozone[45] . These pollutants can cause respiratory problems, including asthma and chronic lung disease.[46]

Italy has been under infringement procedures for air quality violations—particularly concerning particulate matter (PM10 and smaller)—for several years. The situation is only worsening, with

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[43] Systemiq. *Global ETES opportunity*. Systemiq, 2024

[44] Clean Air Task Force. *24/7 Carbon-Free Energy: how Europe can and should ensure clean electricity*. Clean Air Task Force,

[45] European Environment Agency. *Guidance 2023: Part B, Sectoral Guidance Chapters, 1A: Energy Industries.EMEP/EEA* European Environment Agency, 2023

[46] Centres for Disease Control and Prevention. "ToxFAQ on cadmium". US Department of Health and Human Services. Accessed in 2024

another infringement procedure initiated in April 2024 due to continued and improper application of existing directives.[47]

Electrifying industrial heat would eliminate local pollutant emissions, actively contribute to improved air quality and reduce secondary pollutants in the atmosphere.

It is important to note that while biomethane is considered 'climate neutral', it cannot be considered as such with regard to local pollutant emissions. Its chemical composition is exactly the same as fossil methane and therefore its application would not contribute to solving the problem of local pollution.

Furthermore, literature sources indicate that methane emissions along the biomethane and biogas supply chains may be underestimated[48] , raising concerns about their true decarbonisation potential.

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[47] Ministry of Foreign Affairs and International Cooperation. State of Infrastructure. Italian Ministry of Foreign Affairs, 13 March 2024.

[48] Semra, Bakkaloglu, Jasmin, Cooper, Adam, Hawkes, 2022. One earth, Volume 5, Issue 6, 17 June 2022, Pages 724-736.

5 DISCUSSION OF THE BARRIERS TO ELECTRIFICATION

Despite the technical maturity of electrification solutions for low and medium-temperature process heat, scenario analyses and case studies indicate that industries still face several obstacles to their implementation, ranging from economic to technical and organisational challenges.[49]

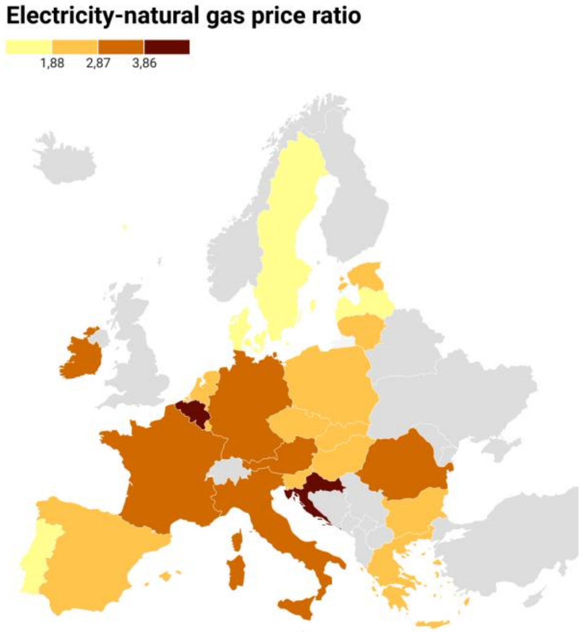
In this chapter, the barriers identified in the scenario analysis and case studies are complemented by insights gathered through the active involvement of various stakeholders via meetings and interviews conducted during the development of this research.

Economic barriers

The economic barriers to electrification are related to the investments involved, their affordability and their sustainability over time.

Higher OpEx than electrified solutions. Currently, the electricity price is higher than that of gas. This disparity arises from the link between the prices of the two carriers, the EU ETS, which currently impacts electricity prices, as well as taxes and levies. This price gap is a major barrier to the electrification of industrial process heat. As shown in the case studies, the fiscal and parafiscal charges on electricity prices make the operating costs of electrified alternatives higher than those of existing gas-based systems[50]. Figure 24 shows that Italy is among the European countries with the highest electricity to gas price ratio.

Figure 24 - *Electricity-gas price ratio for non-residential users. Elaboration by ECCO based on JRC data Heat Pump Market - Country Sheets (2024).*



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[49] The barriers are structured according to the Fraunhofer ISI (2024): 'Direct heat electrification of industrial processes. Potential and future prospects for the EU'. Study carried out on behalf of Agora Industry.

[50] Gas and electricity prices for 2018,

Higher CapEx of electrified solutions for process heat. Today, enabling technologies for electrification have higher costs than those based on fossil fuels. This is particularly evident when considering process heat at medium and high temperature (> 80 °C) and steam processes. Literature studies project a potential cost reduction of around 20% for industrial heat pumps over the next two decades.[51]

Access to finance. The prevalence of small and medium-sized enterprises (SMEs) in the analysed sectors may pose a potential barrier to electrification due to the high fragmentation this can entail, the variety of business strategies and the structural barrier to accessing credit to finance innovation. At the same time, SMEs are often organised in clusters and offer opportunities for rapid responses to market challenges, such as decentralising energy solutions, including the development of renewable energy for self-generation of electricity. However, active support is needed to overcome fragmentation, access to finance, and to address energy supply as an integral component of broader sustainability and competitiveness objectives.

Technical barriers

Technical barriers refer to obstacles and constraints that might limit the adoption of electrification technologies, from connection problems to the impact on finished products.

Infrastructure constraints. The transition to direct electrification requires a significant expansion of the electrical infrastructure. This necessitates adapting and/or expanding existing infrastructure[52] . In addition, investments in electrification involve interactions with administrations and control structures responsible for authorisations, regulatory authorities, and grid distribution and transmission operators, which may lead to uncertainties in the timing of the actual implementation of solutions.

Deep restructuring of the energy supply systems at the plant. Generally, any electrification-related intervention implies a comprehensive analysis of a plant's heat flows, as electrified solutions require the utilisation and recovery of a large part of the available heat flows. The implementation of electrification technologies for low and medium-temperature processes may require the modification of existing process machinery and the redesign of steam or hot water supply systems. The need for such a profound restructuring of heat supply systems is a major barrier, slowing down the adoption of electrification technologies, especially for SMEs. Investment costs must be considered, especially in sub-sectors where margins and profitability may be low (e.g. textiles). Modular approaches, meaning the gradual introduction of electrification technologies into a plant, could help to overcome this barrier, but risk creating investment lock-ins. For example, hybrid systems that integrate natural gas and electrification, such as MVR (mechanical vapour recompression) systems, offer convenience and ease of installation, but risk hindering further investment towards full electrification.

Waste heat availability. The case studies reveal significant opportunities for the industries analysed to exploit unused heat sources within the plant, also presenting a key opportunity for the installation of heat pump-based systems. Where such flows are unavailable at the plant level, district or industrial

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[51] Industrial process heat technology catalogue, Danish Energy Agency, 2024

[52] Fraunhofer ISI 'Direct heat electrification of industrial processes. A technology assessment' 2024, study on behalf of Agora Industry.

site level strategies could offer an alternative to maximise this potential, introducing a shared energy management system. This approach would allow several industries in the same cluster or site to repurpose waste heat from one plant to supply another within the same site.

Product appearance and specifications. Technological alternatives such as dielectric or resistance heating in the sectors analysed could, in some cases, alter product characteristics and appearance, potentially reducing their value and demand. Furthermore, in Italy, some food and beverage products with 'certified origin' must comply with specific production regulations. These regulations safeguard traditional methods and product qualities, governing aspects such as colour, appearance, processing methods and temperatures. Although essential for maintaining authenticity and quality, adherence to these standards can be an obstacle to innovation of production processes. For example, to meet the product specifications of Altamura DOP bread, guidelines indicate that ovens should preferably be wood or natural gas powered. These requirements must be taken into account, as they entail changes to product specifications and consequent bureaucratic procedures. In the sectors analysed, the demand for products is linked to their appearance or feel (industry experts define products as 'alive'). These require a high level of customisation of production stages, for example through a very precise control of humidity and temperature at certain process stages, which constitute the specific know-how of the craftsmanship that characterises the two analysed sectors. Therefore, extensive efforts are required to develop knowledge and skills, starting from an in-depth understanding of processes and sub-processes and how to effectively integrate the electrical carrier, while ensuring precision and control in production stages.

Organisational and administrative barriers

Organisational barriers refer to the general administrative complexity associated with electrification and the need to shift approaches to energy supply system design. They also relate to knowledge gaps and the lack of examples of industrial process electrification and its applicability and effectiveness.

Fragmented legislative framework The Italian regulatory framework appears fragmented and lacks clear medium and long-term strategies and objectives to effectively guide business investments. The current context continues to favour fossil fuel-based solutions and, despite the potential advantages in terms of authorisation times for electric solutions due to their emission neutrality, the lack of clear incentives hinders their adoption. For example, the installation of gas-powered technologies, such as combined heat and power plants, is still classified as an energy efficiency improvement for industries and can benefit from subsidies (Annex III.). This fragmentation is partly due to the absence of an explicit strategic vision at the European level that can be reflected in national policies for the electrification of final heat consumption.

Knowledge gap. As evidenced by the case studies, industrial heat electrification requires a detailed assessment of heat flows and in-depth knowledge of electrification technologies and their functionality. This implies the need for specialised expertise in the design of such solutions and a skilled workforce for their practical implementation, monitoring and maintenance. Furthermore, despite the commercial viability of electrification solutions, there are still a limited number of examples of large-scale applications that could "prove" the reliability of such technical solutions, especially in Member States where energy price formation has historically been favourable to gas, such as Italy.

Adequacy of process-level energy consumption monitoring systems. Despite existing energy efficiency measures, the potential for waste heat recovery remains largely untapped in most industries. As part of the case study analysis procedure (see Annex I), the technical partner assessed the availability of waste heat at sites prior to the design phase of electrification solutions. In most cases, waste heat was found to be available and underutilised. In Italy, residual heat potential, defined as waste heat from industrial processes and captured in heat carriers, is estimated at around 30 TWh/year, one third of which at temperatures below 200°C[53] . This potential represents about 10% of the total final energy consumed by Italian industry in 2021.

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[53] Papapetrou, Michael & Kosmadakis. (2018). Industrial waste heat: Estimating the technically available resource in the EU by industry sector, temperature level and country.

6 STRATEGIC VISION FOR ACTION AT THE EUROPEAN LEVEL

The study conducted on the food and textile sector in Italy shows that electrification represents the most viable option for reconciling decarbonisation with greater energy security and cost-effectiveness from a systemic perspective for industrial process heat. The benefits of electrification are particularly evident in temperature ranges where enabling technologies are already available, namely for low and medium-temperature process heat. This solution would enable zero-emission production processes for all sectors whose emission intensity is exclusively dependent on combustion processes for heat generation, initially at low and medium temperatures.

Despite this, a clear business case for electrification is yet to emerge. Energy-intensive industries typically benefit from discounts on fees and taxes to support their competitiveness, while this is not the case for non-energy-intensive users, which are often small and medium-sized enterprises (SMEs).

Although renewable energy and energy efficiency have specific targets outlined in legislation, the electrification targets needed to meet the EU's climate and energy objectives remain largely implicit in existing national and European frameworks. The publication of the **Clean Industrial Deal** and the Affordable Energy Action Plan, as well as the EU Electrification Action Plan, expected in the first quarter of 2026, provide a strategic opportunity to establish a clear policy framework in support of electrification as a driver of European industrial competitiveness.

To enable electrification as a decarbonisation solution for industry, a coherent policy framework is needed, integrating European and national strategies.

This framework should include **the adoption of an explicit electrification target for industrial process heat,** which breaks down the 32% target set by the Clean Industrial Deal by industry sector. This would give investors certainty about the direction to follow. The clear identification of electrification as a solution capable of ensuring the EU's decarbonisation, energy security and competitiveness could unlock the potential for developing value chains for enabling technologies where the EU is already well-positioned. In addition, it could drive investment on the energy consumer side, guided by a coherent regulatory framework. A European strategy for the electrification of industrial process heat should begin with a comprehensive assessment of existing European and national instruments. This assessment should focus on the effectiveness, synergies and limitations of these instruments, considering the principle of subsidiarity in the division of responsibilities between the EU and Member States.

Member States should therefore **be required to set national electrification targets**, for example, through the Governance Regulation, and should be encouraged to develop targets for grid flexibility, storage and grid development, a roadmap for decoupling the price of electricity from the price of gas, and measures to align energy taxation with climate neutrality goals.

A specific target for the electrification of industrial process heat and the corresponding enabling strategy could also be considered within the framework of the **Industrial Decarbonisation Accelerator Act** as part of the definition of lead markets.
Based on the analyses outlined above, a cross-sectoral target for the electrification of heat generation by 2030 should prioritise areas where electrification technologies are already available and mature.

It is considered theoretically feasible to fully electrify industrial space heating and meet at least 60% of process heat demand below 150°C by 2035, compared to 2021 levels. Thus, the target, expressed as a percentage across all industrial sectors, could be achieved by applying targeted policies to those sectors where electrification is technically feasible.

The decarbonisation target for the most energy-intensive processes would, however, be set beyond 2030 and would benefit both from further innovations, such as medium and high-temperature heat pumps (>150°C), and from the economies of scale and technology transfers already generated by achieving the 2035 target.

Setting an electrification target would require the development of a strategy comprising four main elements:

1. **Accelerating the deployment of renewables in the power sector at competitive prices**. This process is already underway in both Europe and Italy, but constant monitoring and timely responses are needed in case bottlenecks and constraints on renewable energy delivery emerge. Mechanisms should be pursued to further incentivise the deployment of renewables, particularly for industry, by eliminating any investment risks related to lengthy authorisation procedures. Incentives similar to the 'energy release' mechanism should be defined, leveraging the role of industrial operators and their increased investment capacity. The mechanism should also identify ways to include non-energy-intensive companies. Aggregative mechanisms for the demand and management of renewable production, including through capital participation, should be promoted.
2. **Enable consumers to benefit from cost savings due to cheaper renewable energy production.** On the one hand, action should be directed to the wholesale price and the implementation of the **Market Design Regulation** should be pursued to facilitate the decoupling of electricity and gas prices and improve accessibility to long-term contracts, such as Power Purchase Agreements (PPAs) or other forms of contracts to ensure price stability. These mechanisms should address existing economic and financial barriers and broaden access to clean energy contracts for SMEs, including through an active role for the European Investment Bank (EIB). On the other hand, the imbalance in retail prices needs to be addressed. The revision of the **Energy Taxation Directive** should be pursued as much as possible, **rebalancing taxation and tariffs** with the environmental and security externalities of different energy supply systems. In any case, guidelines should be published for Member States to rebalance the price signal of energy products in line with carbon neutrality targets and their respective contribution to energy security, taking into account the **differentiated impact of ETS1 and ETS2 across sectors.**
3. **Expanding and modernising electricity transmission and distribution networks to accommodate increased demand and connection requests in a timely manner.** This also involves addressing the complex challenge of balancing a high-penetration system of intermittent power generation, requiring the development of short and long-term storage systems and of demand response mechanisms. Both are crucial to ensuring that the industry can benefit from a reliable electricity supply without concerns over disconnection. The ongoing development of the **Ten-Year Network Development Plan (TYNDP)** should be closely monitored to ensure consistency with long-term national planning, including the assessment of flexibility requirements and supply and demand scenarios provided by the Commission. This review should also aim to improve **coordination between electricity TSOs and DSOs** and include an assessment of the potential for developing demand response mechanisms and

flexible use of distributed energy resources to enable smart grid operation and to improve cooperation between gas and electricity TSOs and DSOs given gas infrastructure decommissioning plans. Further efforts would also be needed on the ***Grid Action Plan***, in order to accelerate the development and modernisation of networks, and for the development of interconnectors through projects of common interest (PCI) to reduce prices and increase security of supply.

4. **Facilitating the creation of lead markets for zero-emission products** through a set of policies that foster demand for both electrification enabling technologies and zero emission products, including tax incentives and Green Public Procurement (GPP). This would stimulate electrification and create a market for supporting technologies, which in turn would help generate the economies of scale needed to reduce costs and improve international competitiveness.

The study highlights the important role of **training, upskilling, and retraining the workforce**. The full diffusion of electrification solutions can only take place with a **skilled workforce**, capable of developing new technologies and designing their deployment within industrial sites, with all the complexities that this entails in terms of assessing the energy profile of processes, as well as the installation, operation and maintenance of such process electrification solutions. Therefore, despite being mature, such solutions need support in terms of workforce training.

The package of measures presented by the Commission should also establish strategic priorities for a **financial strategy** to facilitate electrification investments related to the above priorities. This should build on initiatives such as the Clean Industrial Deal and include:

- Allocation of dedicated funds for industrial electrification within the next **European Competitiveness Fund** and/or through other dedicated funds, as part of a broader integration of electrification as a decarbonisation solution.
- Stricter enforcement of regulations governing the use of **ETS1 and ETS2** revenues.
- Clear conditionalities for **state aid** with a clear focus on electrification.
- Ensure adequate resources are allocated from the **Innovation Fund** to support the demonstration of innovative direct electrification solutions and the development of smart grids, with a focus on small-scale projects and those involving SMEs.

For many European countries, and certainly for Italy, the limited fiscal space due to high national debt levels restricts the ability to secure the necessary financing for the transition. This also affects the spending needed to unlock the potential of direct electrification of industrial heat, as it requires public funding to accelerate private investment to achieve the widespread adoption of these technologies at a pace compatible with achieving net zero by 2050.

Current financing schemes for industrial transformation in Italy are mainly linked to REPowerEU, as shown in Annex III.
Incentives help to increase demand for new technologies, making them affordable at market prices.

These incentives should be phased out, but the funding period of the National Recovery and Resilience Plan, which ends in 2026, may be too short to achieve this, potentially limiting its effectiveness in stimulating private investment. Therefore, structural measures are urgently needed to address the limited financial capacity of the most indebted Member States.[54]

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[54] https://eccoclimate.org/a-european-sovereign-fund-for-the-climate-transition/

7 POLICY RECOMMENDATIONS FOR ELECTRIFICATION IN ITALY

This report shows the need for a clear strategy to address the electrification of Italian industry. The strategy should combine actions to enable nationwide electrification across all end uses, rebalancing the price of energy raw materials in line with climate and energy security objectives.

An electrification strategy for Italian industry should implement actions to address the barriers identified in Chapter 5 (economic, technical and knowledge barriers) that businesses, and in particular small and medium-sized enterprises (SMEs), face when deciding to electrify their consumption.

Actions promoting industrial electrification apply to all sectors; therefore, data provided on the food and beverage and textile sectors can help draw conclusions that could be effectively applied to all industries or processes using heat at low and medium temperatures.

A national electrification target for industrial process heat could clearly identify electrification as the preferred option for industrial process heat, especially for temperature ranges where technologies are already available on the market. **The Italian industrial strategy, currently under development, should therefore include a national electrification target for industrial process heat**.

Looking at the data, this cross-sectoral target should take into account the different starting points and technological availability of various temperature ranges and processes of the manufacturing sectors, as some processes are immediately electrifiable, while those at higher temperatures (e.g.> 500°C) may not be electrifiable at all. In 2021, Italy's industrial electrification rate stood at around 40%, and estimates suggest that an additional 30%, to reach **70% by 2035** compared to 2021, could be considered feasible, provided that the enabling conditions (primarily, the development of renewables and grids) are in place. This is in line with our recommendations for a European-wide target, focusing on the electrification of areas where solutions are already mature and available, such as **100% of space heating** and **60% of process heat below 150° that has not yet been electrified.**

1. Cross-cutting actions enabling electrification as a solution for competitiveness

1.1 Decoupling electricity and gas prices - Enabling the penetration of renewables into the energy system increases the stability of industrial energy supply prices and reduces their volatility. This requires a market design capable of transferring the price advantages of renewables to end consumers, accompanied by a comprehensive grid development, with increased capacity and resilience, and better integration and planning between DSOs and TSOs[55] . This decoupling could be accelerated by adopting new products for long-term price contracts, such as 24/7 power purchase agreements (PPAs)[56] or contracts for difference. Demand aggregation mechanisms through capital participation could also allow smaller customers to act as counterparts to a purchase contract.

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[55] Terna, "Pilot Project for TSO-DSO Coordination". *Terna*, December 2023

[56] Clean Air Task Force. *24/7 Carbon-Free Energy: how Europe can and should ensure clean electricity. Clean Air* Task Force, 2024

1.2 **Energy tariff reform -** Currently, industrial competitiveness is based on the greater affordability of gas compared to electricity. However, considering the projected prices of gas and CO_2, it is estimated that energy supply costs for businesses will rise significantly, also in terms of volatility. In this context and given the progressive decoupling from the real cost of renewable energy production, electrification emerges as the solution offering the lowest cumulative cost increase between 2025-2050, as shown in Figure 23. The gas price projections in the scenario analysis, although based on established assumptions, are subject to high uncertainty, especially in the long run. Therefore, safeguarding policies should reflect the respective contribution of both energy carriers in terms of decarbonisation and energy security in their pricing, in order to restore the foundations for industrial competitiveness. **A strategy is needed to redistribute fiscal and parafiscal components (i.e. ETS, general system charges and additional components) and rebalance the relationship between electricity and gas price levels.** This would provide certainty of return on investment for electrification and make electricity the most secure energy commodity, both for climate and energy security reasons.

2. Targeted actions for industrial electrification

2.1 Addressing economic barriers

2.1.1 **Funding schemes fully aligned with the Net Zero perspective -** There are electrical solutions (e.g. heat pumps) capable of covering higher temperature ranges than those evaluated in the study. However, the application of these technologies is still limited and site-specific. The scenario analysis shows that supporting the installation of these technologies, promoting energy efficiency and providing CapEx incentives is crucial for the development and early adoption of the most efficient electrification solutions, reducing overall investment costs. In fact, the lowest cost scenario is the one in which incentives are provided to reduce the capital investment of efficient steam electrification technologies. To facilitate the adoption of electrification technologies, initial financial support is needed to promote early stages of diffusion in the relevant sectors and scale up production. Policy instruments should support the necessary capital investments for electrification technologies. New or renewed financing schemes, such as the upcoming ***Conto Termico 3.0*** (see Annex III) and the revised white certificate scheme, should have a medium-term perspective and clearly exclude fossil gas-based solutions not aligned with the Do No Significant Harm (DNSH) principle. To maximise impact, such schemes should always be accompanied by energy efficiency requirements.

2.1.2 **Creating lead markets for zero-emission products -** A careful evaluation of possible emission requirements for national green public procurement criteria could be a way to stimulate demand for 'green' products and indirectly support investments in electrification. This is particularly important in light of the upcoming revision of the public procurement directive at the European level. Such policies should come with a careful assessment of the reference market for final products in order to be able to focus on effective incentives.

2.2 Addressing technical barriers

2.2.1 **Overcoming infrastructural constraints -** Accelerating and streamlining authorisation procedures and the use of existing capacities. Providing better visibility and coordination among all actors involved in grid development, including TSOs, DSOs and industrial operators within national development plans. It is also considered important to initiate a process for the construction of grid connections that ensures decarbonisation while also guaranteeing economic efficiency.

2.2.2 Improving cooperation at cluster or industrial site level - As seen in the case studies, the availability of waste heat facilitates the adoption of efficient electrical solutions for heat temperatures above 80°C. The integration of heat networks in industrial clusters or sites could help overcome technical barriers, such as the lack of waste heat in some industries, to maximise heat generation efficiency and promote the optimisation of energy consumption on a larger scale. For instance, Italy is characterised by many specialised 'districts' that could share resources for energy supply mechanisms, fostering cooperation in industrial clusters and extending the concept of energy communities to heat. Such initiatives could favour the direct electrification of industrial clusters, considering the entire production ecosystem and different enterprises involved, leading to highly efficient solutions and enabling the sharing of the initial investment required.

2.3 Addressing knowledge barriers

2.3.1 Integrating training, upskilling and retraining within financing programmes - Financing programmes should allocate part of their resources to training. A wide range of professionals, from engineers and installers to financial institutions and banks, must be fully aware of the broader technical, regulatory, and financial opportunities of electrification to unlock its full potential. This could be achieved through collaborations with stakeholders, who should be actively involved in policy design using an efficient and structured multi-level participation process.

2.3.2 Creating knowledge 'Catalysts' - Electrifying industrial process heat requires in-depth knowledge of electrification solutions and how they can be implemented safely, efficiently, and effectively. Policies should include training and education programmes, as well as the presentation of success case studies to encourage replicability and build confidence in electrification as a secure solution for industrial energy supply. Industry associations and energy service companies (ESCOs) can play a significant role in promoting electrification as a decarbonisation solution; therefore, specific support should be provided to them to offer clearer and up-to-date financing opportunities, as well as the most advanced technical solutions. Industry alliances and associations are essential for spreading and replicating knowledge, especially for SMEs.

2.3.3 R&D funding schemes – Support schemes should be pursued for R&D projects in enabling technologies for electrification. Such technologies would include the large-scale deployment of heat pumps above 200°C, as well as other enabling solutions such as electrification through electrothermal storage systems. At the European level, part of the funds allocated through the Innovation Fund **should be earmarked for electrification enabling technologies,** ensuring that both large companies and SMEs have access to these funds.

ANNEX I: CASE STUDY CHECKLIST

1. **Identify temperature requirements**
    - Check delivery method
        - Hot water, superheated water, steam?
    - Evaluate temperature needs
        - Are there uses with significantly lower temperatures compared with the temperature in which heat is provided?
            - If yes: disconnect from main distribution and connect to a lower temperature generator.
    - Low temperature uses (<55°C)?
            - If yes: suited for heat pumps at low temperatures (<55°C)
2. **Check waste heat flows**
    - Are there unused waste heat flows >20°C?
            - If yes: use as source for heat pump.
    - Evaluate flow type of waste heat flows
            - Liquid preferred for smaller and more efficient heat exchangers.
            - Ensure consistency of flows over time.
3. **Heat pumps sizing**
    - IF low-temperature loads (<55°C) or significant medium temperature waste heat sources.
        - Sizing of heat pump:
            - If primary source of heat: 1.5/2 times peak load.
            - If backup source: size for peak load.
        - Evaluate efficiency using heat pump providers technical sheet- efficiency depends on temperature difference (max 90°C lift).
            - COP > 3.5/4 for competitiveness with natural gas.
        - Assess cost variation
            - Supply temperature affects cost.
            - If external air evaporator is used: higher cost (+10%) and variable COP.
4. **Temperature profile**
    - Evaluate heat generation potential by heat pumps and daily fluctuations of heat demand
        - If not simultaneous: implement storage system (through a hot water tank).
5. **Steam generation**
    - Evaluate electrification options.
        - IF heat sources at >40/50°C
            - Possible to use heat pumps with boosters for 110°C steam.
        - ELSE electric boiler for steam generation
    - Select the most cost-efficient option
6. **Process specific technologies**
    - Is waste available onsite for biogas production?
    - Are there specific technologies for certain processes that could be substituted by electric-based alternatives?
    - Select the most cost-efficient option

Other Assumptions

Specific heat of water = 4.18 kJ/(kg*K)

Lower heating value of natural gas = 9.59 kWh/Sm^3

Cost of natural gas (average in 2023 for industrial entities) = 0.5 €/Sm^3

Cost of electricity (average in 2023 for industrial entities) = 0.2 €/kWh
Specific emissions of natural gas = 1.991 $kgCO_2/Sm^3$
ETS (Emissions Trading System) quota price 2024 = 73 €/ton
Electricity to TEP (Ton of Oil Equivalent) conversion factor = 0.000187 TEP/kWh
Natural gas to TEP conversion factor = 0.00082 TEP/Sm^3

ANNEX II: MAIN CASE STUDY RESULTS

Table - *Main case study results on dairy industries.*

	Case 1: SME cheese producer	**Case 2: SME cheese and butter producer**	**Case 3: Large dairy enterprise**
Approximate quantity of milk processed per year [litres/year].	46 100 500	35 500 885	600 000 000
Total demand for process heat [MWh/a].	2 370	1 202.8	40 000
Steam demand [MWh/a].	1090	240.6	2680
Final consumption			
Gas - current [MWh]	2 720	4 924	51 600
Electricity-electrification [MWh	1 539	2 039	14 745
Overheads			
Electrification [€]	750 000	1 500 000	8 000 000
OpEx			
OpEx - current [€/a]	137	250	2 813 642
OpEx - electrification [€/a]	384 737	509 585	3 693 642
Primary energy consumption			
Current [GJ]	8653	15 758	162
Electrification [GJ]	12 038	15 925	115 493
Current [tonCO_2/a]	547	999	11 903
Electrification [tonCO_2/a]	0	0	0
ETS1 applies [Y/N].	N	N	Y

Table - *Main case study results on the brewery.*

Total process heat demand [MWh].	20 000
Steam demand [MWh]	3400
Final consumption [MWh/a]	
Gas - current [MWh/a	22 913
Electricity - electrification [MWh/a]	10 800
Biomethane - biomethane [MWh/a]	11 491
Electricity - biomethane [MWh/a]	3500
CapEx	
Electrification [€]	4 000 000
Biomethane [€]	5 000 000
OpEx	
Current [€/a]	1 050 000
Electrification [€/year]	3 500 000
Biomethane[€/year]	875 000
Primary energy consumption	
Current [GJ]	71 979
Electrification [GJ]	84 436
Biomethane [GJ]	51 498
Emissions	
Current [tonCO_2/a]	4181
Electrification [tonCO_2/a]	0
Biomethane [tonCO_2/a]	1045
ETS1 applies [Y/N].	N

Table - *Main results of case studies on textile industries.*

	Case 1: Wool dyeing enterprise	**Case 2: Wool production enterprise**
Total process heat demand [MWh].	11 250	19 842
Final consumption [MWh/a]		
Gas - current [MWh/a]	12270	21378
Gas - electrification [MWh/a]	0	608
Electricity - electrification [MWh/a]	10 050	17 120
Capex		
Current [€]	595 000	565 000
Electrification [€]	675 000	905 000
OpEx		
Current [€/a]	805 000	1 405 000
Electrification [€/year]	1 985 000	3 420 000
Primary energy consumption		
Current [GJ]	42	74
Electrification [GJ]	78	134 178
Emissions		
Current [tonCO$_2$/y]	2486	4337
Electrification [tonCO$_2$/a]	0	124
ETS1 applies [Y/N].	Y	Y

ANNEX III: OVERVIEW OF THE CURRENT POLICY FRAMEWORK FOR ITALY

According to the latest National Energy and Climate Plan, the overall contribution of heat pumps to achieving the renewable energy target for thermal energy represents 30% of total energy consumption for heating by 2030. This contribution from heat pumps is expected to increase by over 70% compared to 2022[57] . However, no specific figures are provided for the electrification of industrial process heat, nor is there an overall strategy identifying electrification as a possible decarbonisation strategy for industry.

However, the national policy framework currently in place in Italy could support the diffusion of electrified solutions, through policies and schemes promoting energy efficiency, but it appears fragmented, complex and partly contradictory.

As national schemes are not subject to clear conditionalities, such as the Do No Significant Harm (DNSH) principle, some measures still support the diffusion of fossil fuel-based technologies (e.g. the White Certificate Scheme, the Conto Termico).

In contrast, measures under REPowerEU[58] , such as Transition 5.0, adhere to the DNSH principle and thus exclude fossil fuel-based technologies. However, these funds will expire in 2026, and some initiatives are not yet operational, which limits their impact.

Finally, the national transposition of the latest revision of the EU ETS directive indirectly establishes an incentive system for the electrification of energy supply systems. Furthermore, plants that typically do not fall under the scope of the directive due to their size (i.e. below 20MWt of installed thermal capacity) can temporarily opt to join the scheme and use the free allowances to partially repay their investments, following renovations and electrification of the energy supply system.

The following table summarises the measures that directly or indirectly support the electrification of industrial process heat in Italy.

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[57] Table 13 on the updated NECP2024

[58] Repower EU and PNRR MIMIT review - EU Commission approves new measures Repower EU and PNRR MIMIT review - EU Commission approves new measures

***Table -** Existing policies and measures directly and indirectly supporting electrification in Italian industries. Transposition of EU policies with immediate effect on the national context is also considered.*

Measure	Description	Type of support	Duration
National transposition of EU ETS [59]	More than 1 200 installations in Italy are covered by the ETS. The national transposition reflects the latest version of the directive, which allows operators to maintain free allocation if installed thermal capacity falls below 20MWt, thus helping to finance investments in electrification.	Direct Economical	As of 2026
Conto termico[60]	National direct incentive scheme for the installation of small-scale thermal energy from renewable sources. The scheme is under revision and should also include the industrial sector.	Direct Economical	Under
White certificates scheme[61]	National scheme to incentivise energy efficiency through reimbursement based on the monitoring of energy savings. The scheme is under review.	Direct Economical	Under review
Transition 5.0[62]	Italian tax credit to support the purchase of new technologies to support decarbonisation strategies. 6.3 billion, financed through REPowerEU.	Direct Economical	2026
Support for Net Zero technologies[63]	Grants, loans and rebates worth 2 million euros to boost private investments in energy efficiency and sustainable production. Funded by REPowerEU	Direct Economical	2026
Supporting the competitiveness and resilience of strategic supply chains[64]	Grants and loans of 0.5 million euros to strengthen strategic industrial supply chains. Funded through REPowerEU. This measure indirectly promotes electrification by supporting the clean technology supply chain.	Indirect Economical	2026

Incentive schemes for self-generation of electricity from renewable sources are currently in force in Italy and are listed in the table below.

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[59] https://www.gazzettaufficiale.it/eli/id/2024/10/14/24G00163/sg

[60] https://www.consultazione.gov.it/it/le-consultazioni/le-consultazioni-delle-amministrazioni-centrali/decreto-conto-termico/

[61] https://www.mase.gov.it/energia/certificati-bianchi

[62] https://www.mimit.gov.it/it/notizie-stampa/mimit-al-via-il-piano-transizione-5-0-apre-oggi-alle-12-la-piattaforma-per-prenotare-gli-incentivi

[63] https://www.italiadomani.gov.it/content/sogei-ng/it/en/Interventi/investimenti/supporto-alla-transizione-ecologica-del-sistema-produttivo-e-all.html

[64] https://www.italiadomani.gov.it/content/sogei-ng/it/en/Interventi/investimenti/supporto-alla-transizione-ecologica-del-sistema-produttivo-e-all.html

Table **-** *Overview of existing policies favouring self-generation of electricity from renewable sources.*

Measure	Description	Duration
Self-production of RES for SMEs[65]	Non-reimbursable grants to SMEs for the installation of renewable energy self-generation systems. 320 million euros. Funded through REPowerEU.	2026
Energy release mechanism[66]	Early recognition of preferential tariffs for the implementation of self-generation systems of energy from renewable sources.	Ongoing

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[65] Italia Domani. Support for the Self-Production of Energy from Renewable Sources. Italian Government

[66] Ministry of the Environment and Energy Security. *Energy release:* MASE approves GSE Operating Rules. Ministry of the Environment and Energy Security, 2024

THE ITALIAN CLIMATE CHANGE THINK TANK

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