Switzerland
Industry decarbonization through electrification

Potential and impacts of electrification on the Swiss industrial landscape

E-CUBE STRATEGY CONSULTANTS

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Foreword

This study was conducted by Kevin Pahud as a research project at the E-CUBE Strategy Consultants office in Lausanne in partnership with Prof. Rachid Cherkaoui from EPFL.

This study revisits the electrification potential in Switzerland's industrial sector as a key route in achieving net-zero emissions. It reveals that while the industry holds significant potential for electrification, its competitiveness is subject to specific conditions.

A major highlight of this study is the emergence of industrial heat pumps as a cornerstone technology in the electrification process.

While the aim of this paper is to explore the potential of electrification as a decarbonization strategy for Switzerland's industry, it is important to clarify that other solutions, notably biomethane, hydrogen, SMR, and CCUS are also available. However, these are not covered in a comparative analysis with electricity in this report.

Intellectual Property Rights and Limitations of Liability

Switzerland's industry offers great potential for electrification

I. Switzerland's industry consumes around **15 TWh of fossil fuels** and represents 21% of the nation's emissions.

II. Electrification is **technically feasible** with a portfolio of technologies capable of covering the whole temperature spectrum.

III. Switzerland's industry can be **electrified up to 73%**, with half of additions from existing & mature technologies.

IV. The highest electrification potentials can be found in the **low-temperature sectors**.

Electrification is a critical element to achieving net-zero emissions…

V. Electrifying the sector would **decrease final energy consumption by 21%** yet increase electricity demand by 7 TWh annually.

VI. Electrifying the sector could **quarter energy emissions** and reduce them by 45% using only mature technologies.

…but specific conditions apply on its competitiveness

VII. The success of industry electrification is highly dependent on the electricity's competitiveness against alternatives and the cost of CO_2.

VIII. A significant share of electrification can be **profitably achieved with mature technologies**, boasting an average abatement cost of -64 CHF/tCO_2eq.

IX. Considering all technologies, the sector's electrification incurs an abatement cost of 102 CHF/tCO_2eq, largely driven by non-mature technologies.

Industrial heat pumps are set to be the powerhouse of electrification

X. Industrial heat pumps, the backbone of electrification, could profitably **save 5.3 TWh of gas** and 1.7 TWh of LFO.

XI. Cost-competitiveness of industrial heat pumps hinges on **fuel-to-electricity price ratios** and temperature lift requirements.

XII. **Food, beverages, and tobacco would benefit the most** from heat-pumps, by reducing its emissions by 86% profitably.

XIII. The industry sector has aligned with heat pump investments, evidenced by case studies **since 2009**.

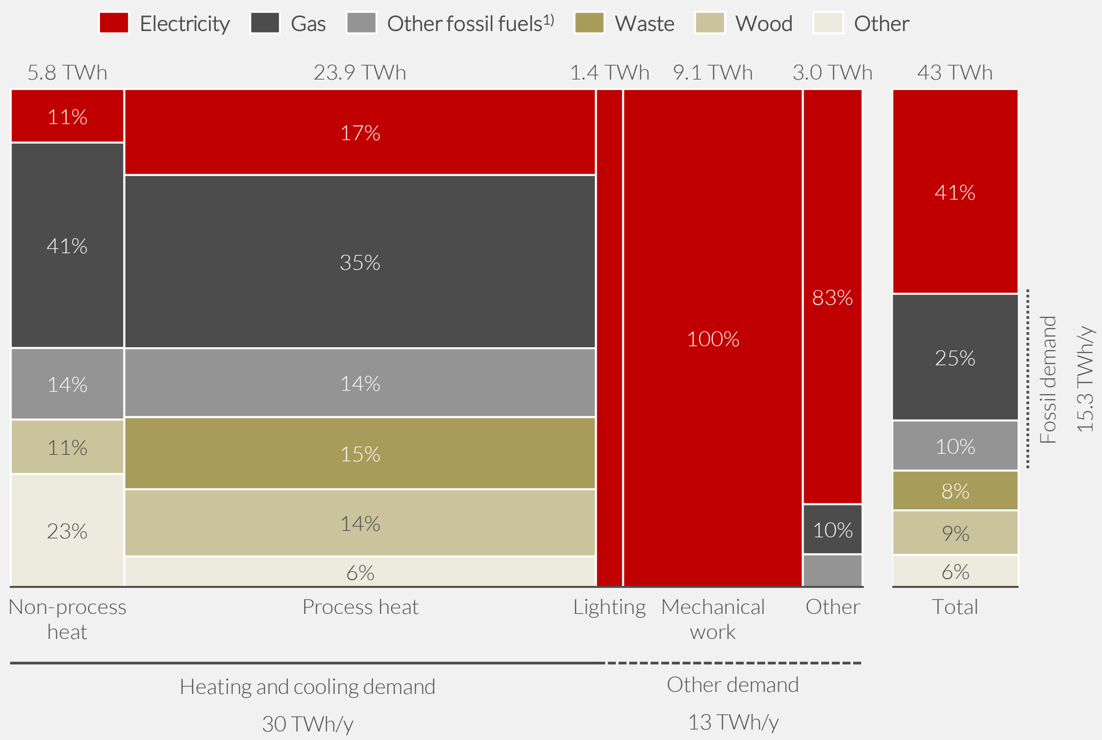
1

Switzerland's industry offers great potential for electrification

Switzerland's industry consumes around 15 TWh of fossil fuels and represents 21% of the nation's emissions.

- Switzerland's industrial energy landscape: In 2021, the industrial sector (which comprises extractive industries, manufacturing, and construction) was responsible for an estimated 19% of the national energy consumption, with a recorded final energy consumption of 43 TWh [1].

Figure 1: Distribution of energy carriers according to end-use demand for Switzerland's industry, in 2021

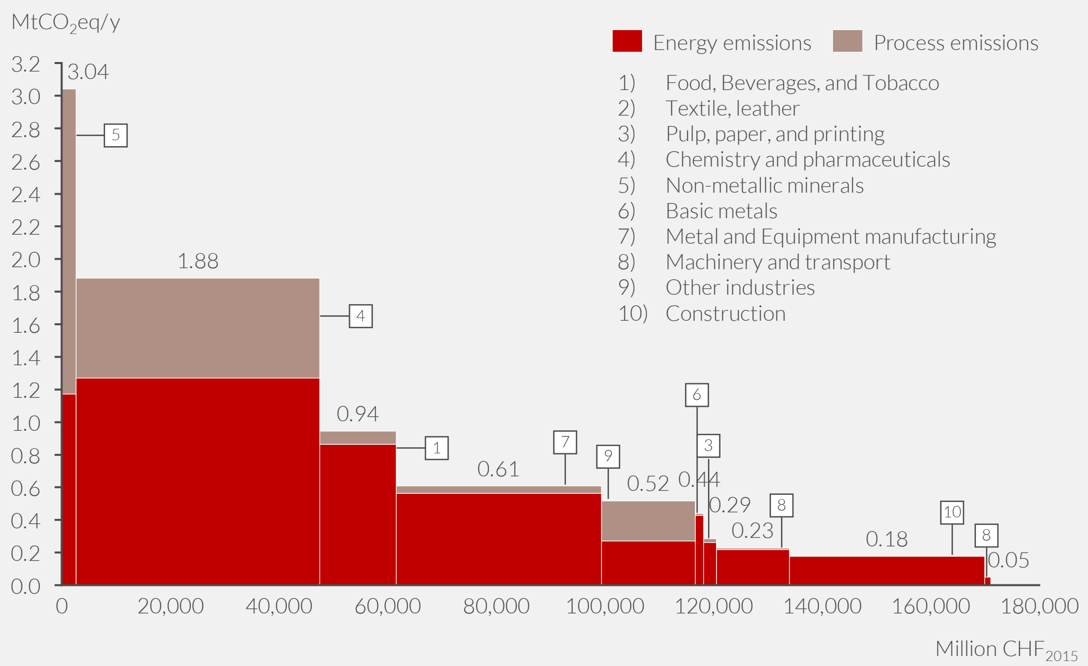


1) Includes: Light Fuel Oil (LFO), coal, and other petroleum derivatives such as naphtha, LPG
Sources: SFOE, E-CUBE Strategy Consultants analysis

- The role of fossil fuels: Fossil fuel combustion accounted for 35% of the final energy consumption, at 15.3 TWh, predominantly to provide process heat. Gas represents the dominant share with a consumption of 11 TWh in 2021, followed by LFO at 2.5 TWh. Since 1990, there has been a discernible decline in the utilization of fossil fuels, marked by a significant shift from oil products (primarily heating oil) to gas, and an increased use of non-fossil fuels such as waste and wood [1].

- **Electricity's current limited coverage for heat:** Electricity constituted 41% of the energy demand, predominantly allocated for cooling and the provision of mechanical work [2] ; it has a more limited coverage in terms of supplying industrial heat, covering only 11% and 17% of the demand for non-process and process heat respectively, which is mainly due to electricity being the sole vector for cooling and Switzerland's steel industry solely based on secondary production with electrical arc furnaces. The predominant carrier for process heat generation is gas, with an annual demand of 8.3 TWh, with a major role in steam generation across all sectors.
- **A small share of emissions:** In 2021, the Swiss industrial sector was accountable for 14% (equivalent to 4.6 $MtCO_2eq/y$) of Switzerland's greenhouse gas emissions attributed to fuel combustion (energetic emissions). When accounting for both process emissions and indirect emissions resulting from electricity[1], this figure rises to approximately 21% of the total emissions, at around 8.6 $MtCO_2eq/y$ in 2021 [3].

Figure 2: **Direct emissions distribution of industry sectors in Switzerland and their respective economic output, in 2021.**



Sources: FOEN, FSO, E-CUBE Strategy Consultants analysis

- **Three sectors constitute around 75% of emissions:** The Non-metallic minerals, Chemistry and pharmaceuticals, and Food, Beverages, and Tobacco, through process and energetic emissions represent around 75% of total emissions from Switzerland's industry in 2021, while covering only 36% of the industry's economic output [4]. Looking solely at energetic emissions (from fuel combustion), metal and equipment manufacturing is added to the three above mentioned sectors to represent 75% of combustion emissions, with around 70% of the economic output.

1. *With a CO_2 intensity of approximately 60 gCO_2eq/kWh for Switzerland's grid, on direct emissions basis for coherence with territorial emissions*

Electrification is technically feasible with a portfolio of technologies capable of covering the whole temperature spectrum.

- **Defining electrification:** Electrification's (i.e., electric technologies) focus is on the direct electrification of heat supply, also known as power-to-heat, excluding indirect electrification methods like power-to-fuels (e.g., hydrogen, methanol). This means the electrification is solely focused on direct heat supply, without altering any process-related energy consumption (e.g., thermal cracking using fossil fuels). As a result, the process emissions are assumed to remain unchanged in the framework of this study, although electric technologies through a redesign of established processes to reduce emissions can be used.
- **Electrical technologies already exist:** Current electrically powered technologies span the entire spectrum of process-heat temperatures, with temperature capabilities surpassing industrial requirements, and with some technologies being already established in industry [5]. Low-temperature heat processes, which are not sector-specific, permit transverse integration through devices like heat pumps or electric boilers to supply heating and cooling [6]. In contrast, high-temperature process heat is highly heterogeneous [7] and necessitates a variety of specific heating systems, as detailed in Table 1.

Table 1: Portfolio of available electrification technologies used for electrification with their associated range of temperature coverage, and applications.

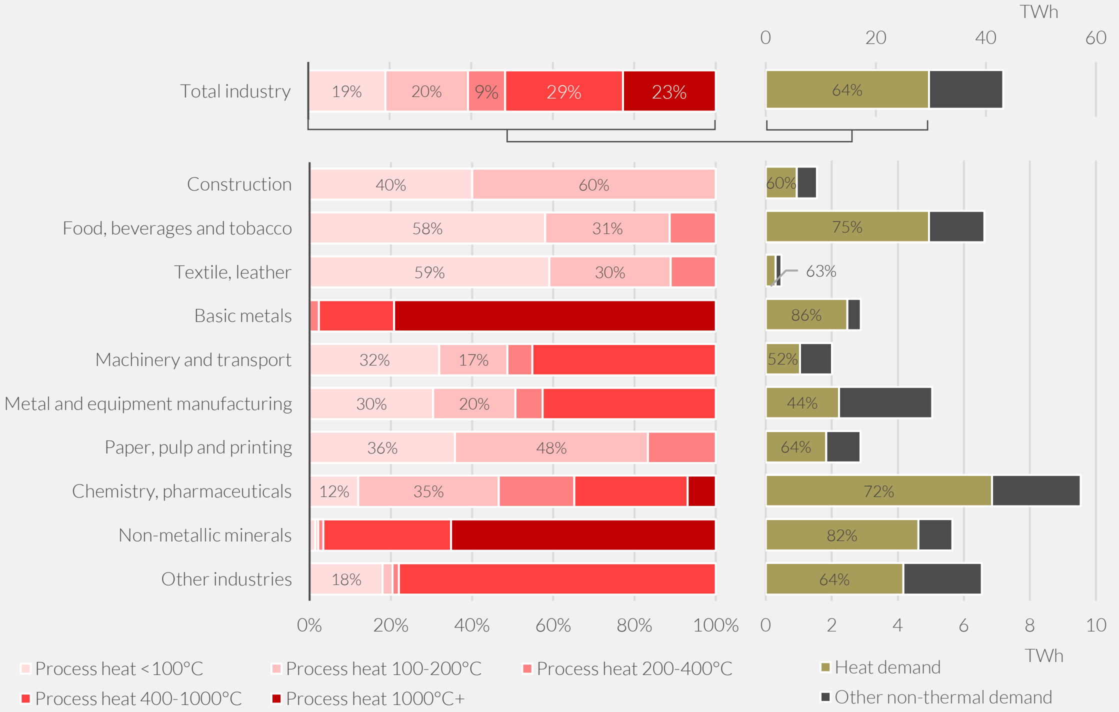
Technology	Temperature range T°C (100 / 200 / 400 / 1000+)	Technological maturity	Applications
Heat pumps	up to 200	Market uptake (<100°C) Demonstration (<200°C)	Hot water, space heating, low pressure steam, drying, washing/cleaning, preheating, food processing, low temperature chemical processes, metal surface treatments, wood processing
Electric boilers	up to 400	Established	Hot water, space heating, thermal distillation, steam
Infrared heaters	1000+	Established (R&D possible for efficiency improvements and cost reductions)	Drying, paint curing, plastics treatment, food processing
Microwave & radio frequency heaters	1000+	Established (except non-metallic industries, and high temperature levels)	Drying, paint curing, ceramics firing and sintering, calcining, cement treatment, food processing, thermal treatments, chemical reaction catalysis
Resistance furnace	1000+	Established	Metals melting, smelting, heaters for chemical industry, distillation, ceramic firing, glass melting, calcination, tempering, annealing
Induction furnace	1000+	Established (R&D possible for efficiency improvements and cost reductions)	Metals melting and smelting, reheating, annealing, welding
Electric arc furnace	1000+	Established	Metals melting, partial refining
Plasma technology	1000+	Established only for waste incineration and metal processing	Waste treatments, metals treatments, sintering, cement production

Sources : IEA, EU-JRC, Madeddu et al., E-CUBE Strategy Consultants analysis

The highest electrification potentials can be found in the low-temperature sectors.

- **Highest potential in low-temperature sectors:** Sectors with highest electrification potentials with mature technologies are found in the Construction sector, food & beverages sector, textiles, and manufacturing[1] sectors, which offer electrification potentials higher than 85%, as seen on Figure 4. Such potential is justified by the sectors' low temperature requirements for their specific processes (see Figure 3), low usage of alternative combustion technologies such as waste or wood (e.g., high waste recovery in the chemistry and pharmaceuticals, and non-metallic minerals industries), and low share of heat demand within total energy demand (e.g., manufacturing industries have heat demand cover less than 50% of their total energy demand). A combination of these three parameters allows for a deeper penetration of electrification technologies. As a case in point, the food, beverages, and tobacco sector, as the 2nd highest energy consumer in Switzerland at ~6.6 TWh in 2021, which has an important share of heat demand, has 89% of its heat demand (at 4.5 TWh) below 200°C, allowing for great electrification potential. Focusing on the whole industry, 64% of its energy demand concerns heat, with 30% of it for processes lower than 200°C.

Figure 3: Distribution of heat demand[1)] per temperature level with respect to total energy demand across industrial sectors for Switzerland's context in 2021



1) Includes heating and cooling
Sources: SFOE, Prognos, E-CUBE Strategy Consultants analysis

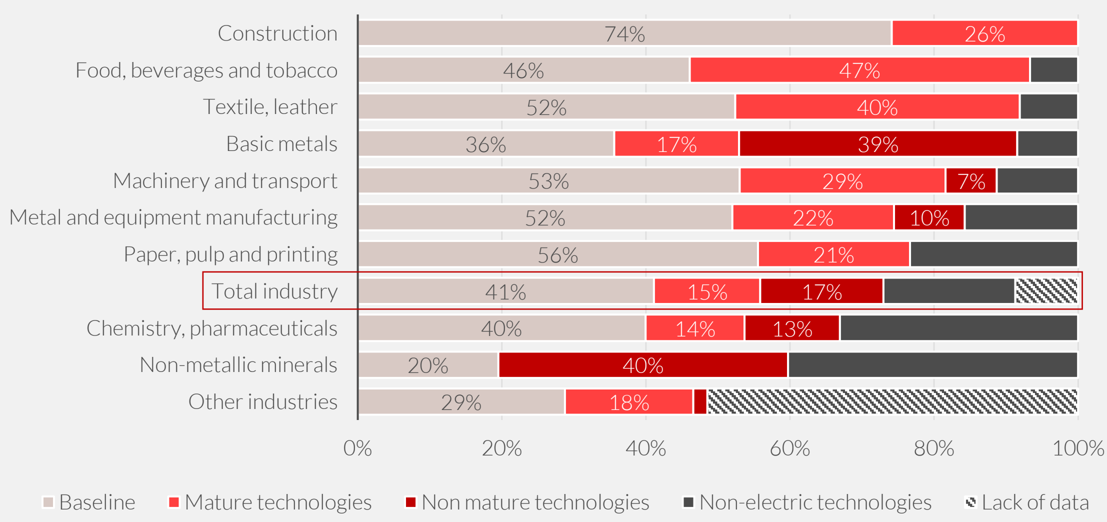
1. *Manufacturing here concerns several sectors such as metal and equipment manufacturing and machinery and transport*

Switzerland's industry can be electrified up to 73%, with half of additions from existing & mature technologies.

- **Multiple stages of electrification:** Electrification is decomposed into three stages, which are designed to illustrate the potential advancements of industry electrification based on the complexity of processes and the maturity of the technologies used. Stage 1 focuses on the non-process heat demand common to all industries, making it the entry point for electrification. It is based on technologies that are mature, well-known, and implemented across various sectors in Switzerland. Stage 2 involves the electrification of process heat demands common to most industries (e.g., drying, washing/cleaning, steam) and still relies on technologies that are readily available on the market and technologically mature. Stage 3 addresses process heat demands specific to a given sector that can be electrified using technologies with lower technological maturities and high-cost uncertainties, especially for heat demand exceeding 400°C.

- **Electrification is defined by constraints:** The electrification potential is limited by specific constraints which are established regarding fuel energy carrier substitution for each sector's process heat requirements, considering economic and industrial conditions. These constraints concern specific fossil fuels for processes such as oil derived products, or waste recovery within industries. Non-fuel non-electricity energy carriers, such as solar heat or district heating, are kept and not replaced by electricity, whether process or non-process heat. Hence electrification here denotes the constraints-adjusted electrification potential, to ensure a realistic approach towards technology switching.

Figure 4: Electrification potential of Switzerland's industries according to technology maturity



Sources: E-CUBE Strategy Consultants analysis

- **Electricity potential covered by mature technologies:** The electrification of Switzerland's industries can largely rely on mature technologies currently available on the market. These technologies account for 46% of the additional electrification potential and 56% of the electricity technologies present in the industry energy system. Technologies that are not yet mature, particularly those addressing high-temperature process heat and core-process streams, offer the potential to provide an additional 17% of electricity coverage.

Methodological framework

- **Goal and scope of the study:** The primary aim of this analysis is to assess the impact of electrification on Switzerland's industrial sector, particularly in relation to achieving climate goals and enhancing energy efficiency, while also considering the financial implications. This study also identifies the conditions necessary to maintain the competitiveness of electrification. The strategy involves transitioning to electric devices to improve energy efficiency, thereby reducing energy demand and emissions. For this analysis, 'industry' encompasses all economic activities classified under NOGA codes 5 through 43, which include extractive industries, manufacturing, water and waste management, and construction. 'Energy' is defined as final energy, referring to the energy purchased and received by consumers. When referring to heat demand, it implies useful energy that fulfils a specific service for the user. Process heat, or heat demand, encompasses both heating and cooling requirements.

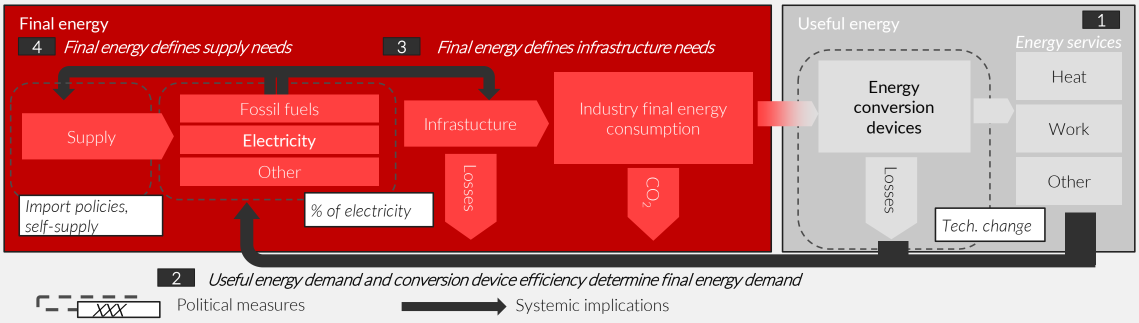


Figure 5: Overview of the energy balance of Switzerland's Industry with systemic implications from energy demand

- **The electrification model:** The study relies on the development of an electrification model, which encompasses data collection and wrangling, energy (and associated economic and emissions outputs) mapping, electrification and its impacts, and finally financial analysis.
  - **Data sources:** The foundation of the study is built upon a bottom-up sub-model, which involves acquiring extensive datasets from established databases and industry stakeholders, with missing data filled from the literature.
  - **Energy demand & emissions mapping:** The electrification model encompasses all drivers to establish a complete dataset of the energy and emissions consumption in the industry by sector, end-use and energy agent, through a diverse range of constraint satisfaction problems, and allocation sub-models.
  - **Electrification impact:** The electrification model is divided in three stages of electrification and employs a recursive algorithm to calculate energy consumption and emissions, for each industry sector, through integration of different industry constraints, technology capabilities and limits.
  - **Financial analysis:** Techno-economic analysis is based on a discounted cash-flow model that leads to different use cases for the study. All electrification projects are designed as brownfield investments upon end-of life of existing assets, with fuel costs from historical averages and technology costs from 2021-2022. CO_2 taxes are defined as post-combustion taxes (e.g., EU ETS) that are not included in the initial cost of fuel and set at 120 CHF/tCO_2eq.

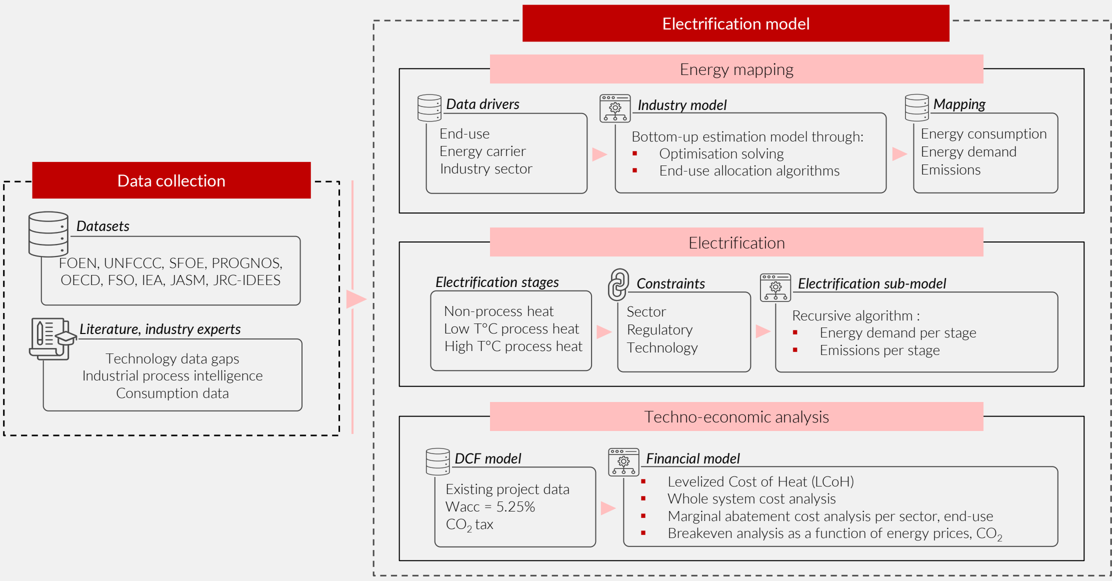


Figure 6: Global overview of Switzerland's industry electrification model

2

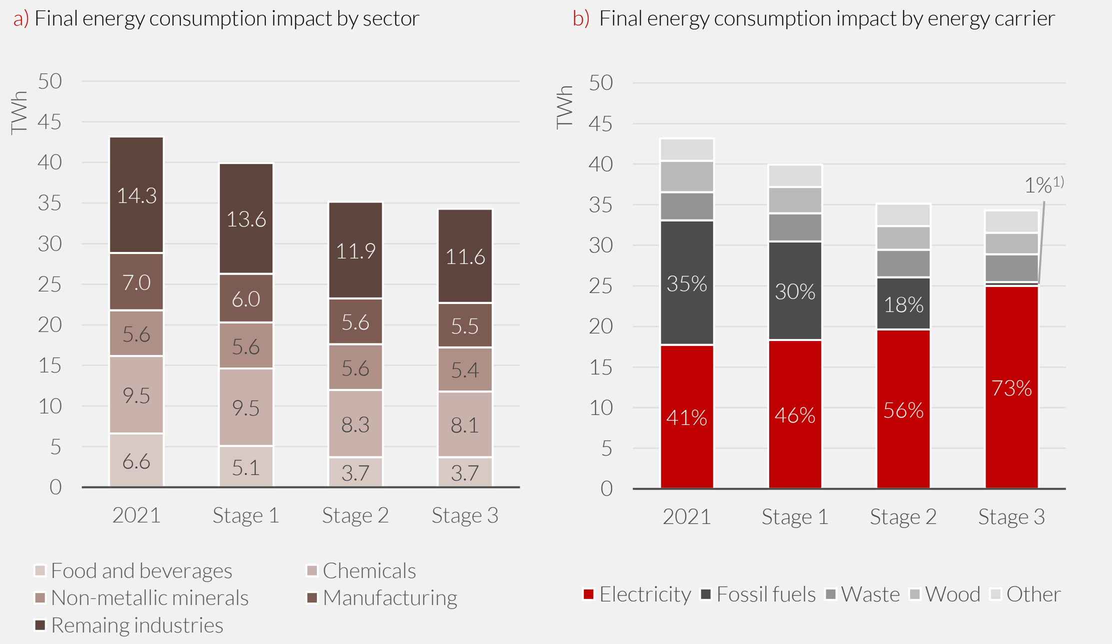
Electrification is a critical element in achieving net-zero emissions…

Electrifying the sector would decrease final energy consumption by 21% yet increase electricity demand by 7 TWh annually.

- Increase electricity to reduce energy demand: By electrifying up to 73% of the industry, the annual final energy consumption can be reduced by 21%, dropping from 43 TWh to 34 TWh. This significant decrease is attributed to the efficiency gains offered by electric technologies, which provide the same energy service but with lower energy input. However, this reduction in energy consumption is accompanied by an increased demand for electricity, projected to rise by 41%, resulting in an annual consumption of 25 TWh/year for the industry sector. As depicted in Figure 7, the most substantial increase occurs in Stage 3 of electrification, which involves less efficient conversion technologies due to the high-temperature requirements. Accordingly, electricity could then account for 48% of non-process heat and 57% of process heat.
- Increased demand must be met with increased low-carbon generation capacity: Switzerland's power grid is predominantly decarbonized, largely due to its reliance on nuclear and hydropower. However, for the electrification of the industry sector to be effective, it should be coupled with carbon-free generation, particularly from renewable sources. Currently, new renewable capacities in Switzerland generate approximately 6 TWh, which constitutes only 24% of the energy required for a fully electrified industrial sector. The consistent expansion of carbon-neutral power generation becomes indispensable for emissions reduction through electrification as insufficient generation capacity could delay the retirement of emission-intensive technologies.
- Biggest impacts per sectors: Every sector experiences a reduction in total energy demand due to the efficiency improvements associated with electrification. The most significant decrease is observed in the Food, Beverages, and Tobacco sector, which sees its energy demand drop by 44%, from 6.6 TWh to 3.7 TWh per year. This reduction is coupled with a 31% increase in electricity consumption. However, energy-intensive sectors and those with high-temperature requirements exhibit the smallest reductions in energy demand. This trend is particularly evident in sectors such as basic metals and non-metallic minerals.

- **The role left for fossil fuels:** The electrification of Switzerland's industry up to stage 3 results in fossil fuels accounting for only 2% of process heat demand and being eliminated from non-process heat demand, as seen on Figure 7. Gas and Light Fuel Oil (LFO) are no longer in use and are entirely substituted by electricity. The remaining fossil fuels (coal for metals and LPG/naphtha for thermal cracking) are employed for high-temperature processes >400°C. Fossil fuels, which represent 35% of total energy demand today, are reduced to 1% of final demand, accounting to a yearly consumption of 0.4 TWh. Focusing solely on mature technologies (up to stage 2), fossil fuels are reduced to 18% of final consumption (6.4 TWh), of which 4.2 TWh are gas. By concentrating only on non-process heat only (stage 1), fossil fuels can be reduced to 30% of final energy consumption.

Figure 7: Evolution of Switzerland's industry's final energy demand through electrification



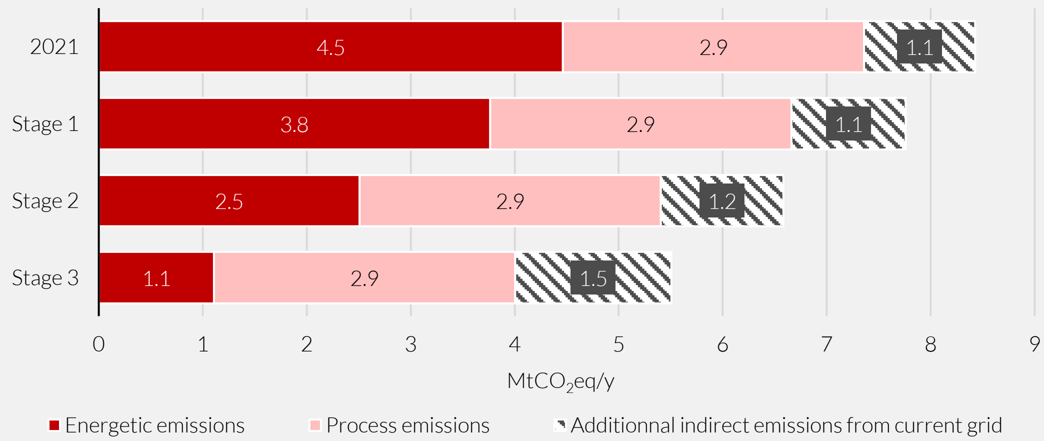
1) Concerns the remaining fossil fuel demand for all end-uses, focusing on process-heat only (i.e., the only end-use for which fossil fuels remain), they represent 2% of the demand.
Sources: E-CUBE Strategy Consultants analysis

- **What is biomethane and hydrogen's role in industry decarbonization?** While electricity is a key low-carbon alternative to fossil fuels, several thermal solutions based on hydrogen or biomethane with varying degrees of maturity are also available. Despite not being the scope of this study (as stated in the foreword), industrial processes requiring high-temperature heat (over 400°C) and those with residual emissions (process or not) present a potential area for the future growth of these fuel demands. Their economics could become competitive with electrical technologies, particularly given the lower thermal efficiencies of current electric devices at very high temperatures. However, as of now, there is virtually no hydrogen production dedicated specifically for this application [8], and biomethane production is limited in Switzerland, requiring strong dependencies on imports. Despite having economics more expensive than bioenergy, hydrogen holds the potential to aid in decarbonizing the more geographically dispersed segments of industrial high-temperature heat demand. This is especially relevant in situations where direct application of Carbon Capture, Utilization, and Storage (CCUS) may be impractical, or if the supply of sustainable bioenergy is limited. Nonetheless, similar to the challenges faced by electrical technologies for high temperature heat, pure hydrogen cannot easily replace coal or natural gas in many industrial sectors due to the diverse and specific requirements of energy conversion devices [9], whereas biomethane offers easier integration to existing heat technologies.

Electrifying the sector could quarter energy emissions and reduce them by 45% using only mature technologies.

- **The impact on energetic emissions:** Electrification of fossil fuels not only results in efficiency gains but also depends on a reduction in emissions. By focusing on energetic emissions, hence combustion related emissions, electrifying the sector can divide such emissions by four, thus reaching around 1.1 $MtCO_2eq$ per year from the current 4.5 $MtCO_2eq$ per year. Focusing solely on mature and available technologies, hence stage 1 & 2 mitigation strategies, energy emissions can be reduced by 45%, to 2.5 $MtCO_2eq$ per year. Residual combustion emissions result from remaining fossil fuel combustion and waste heat recovery.
- **Electrification in the broader context of emissions:** Emissions reductions are to be considered in the broader context of emissions, hence integrating process emissions and indirect emissions, Power-to-heat technologies, here focus on direct heat provision and do not interfere with process emissions, hence their mitigation requires a different strategy, and remains unchanged at 2.9 $MtCO_2eq$ per year, covered at 86% by Non-metallic minerals and Chemicals sectors. These electrifiable emissions can offer opportunities through CCUS (as these sectors have important emissions from waste and processes) or above mentioned low-carbon alternatives such as H_2 or bio-CH_4.

Figure 8: Evolution of Switzerland's industry's emissions, by emission type through electrification, with the inclusion of indirect emissions through electricity1)



1) Indirect emissions assume a current grid at 60 gCO_2eq/kWh for industrial consumers on Switzerland's grid based on direct emissions assumptions as direct and process emissions are extracted from territorial emissions and not on a carbon footprint basis
Sources: OFEV, E-CUBE Strategy Consultants analysis

- **The importance of a low-carbon grid:** The global emission impact of electrification is critically dependant on the carbon intensity of Switzerland's grid. In the absence of further decarbonization of the power supply, electrifying the industry can decrease all emissions by 37%, to a remaining approximately 5.5 MtCO_2eq. With a fully decarbonized grid, Switzerland's industry total emissions could decrease by 52%, reaching 4 MtCO_2eq per year. Focusing solely on mature technologies, Switzerland's industry could achieve a reduction of 22% in total emissions, and 36% if its grid is fully decarbonized.
- **Sectoral improvements:** Emission reduction potentials per sector are dependent on their carbon intensities. Low CO_2 intensity sectors such as Food, Beverages, and Tobacco, and manufacturing (all sectors combined) offer important emission reduction potential, similarly to the basic metals sector (as no primary steel production exists in Switzerland). As a case in point, the Food, Beverages, and Tobacco sector has the potential to reduce its emissions by 86%, with a heavy penetration of heat-pumps. Sectors with important shares of process emissions offer overall smaller mitigation results and would require alternative technologies.

3

…But specific conditions apply on its competitiveness

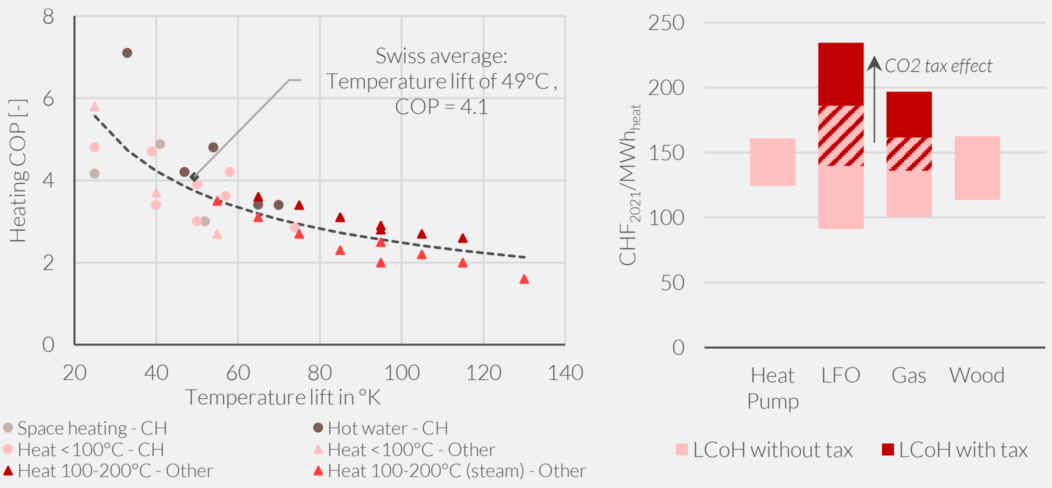
The success of industry electrification is highly dependent on the electricity's competitiveness against alternatives and the cost of CO_2.

- **Electricity's competitiveness:** Electricity based technologies are inclined to higher investment costs than their counterparts and rely on higher energy costs as opposed to alternatives. To ensure competitiveness of such technologies, capital costs should decrease, and appliance performances should be high to limit electricity's higher cost per energy unit (figure 9.a). Electrical technologies lose performance as operating temperatures go higher, the breakeven point is, with current technology maturities, at operating ranges between 100-200°C (figure 9.b). Hence sectors such as food, beverages, and tobacco are key for areas for heat-pump integrations. Ensuring appropriate CO_2 taxation mechanisms (e.g., EU ETS) enables electrical technologies to have financial costs similar to alternative fossil fuels, despite lower performances of electrification devices.

Figure 9: Factors influencing electrical technologies' competitiveness.

a) Industrial heat pump heating Coefficient of Performance (COP) as a function of required temperature lifts for existing industry projects[1] in Switzerland (CH) and other regions (Other).

b) Levelized Cost of Heat[2], (LCoH) with, and without a CO_2 tax of 120 CHF/tCO_2eq, for brownfield process heat generation at 100-200°C operating ranges.



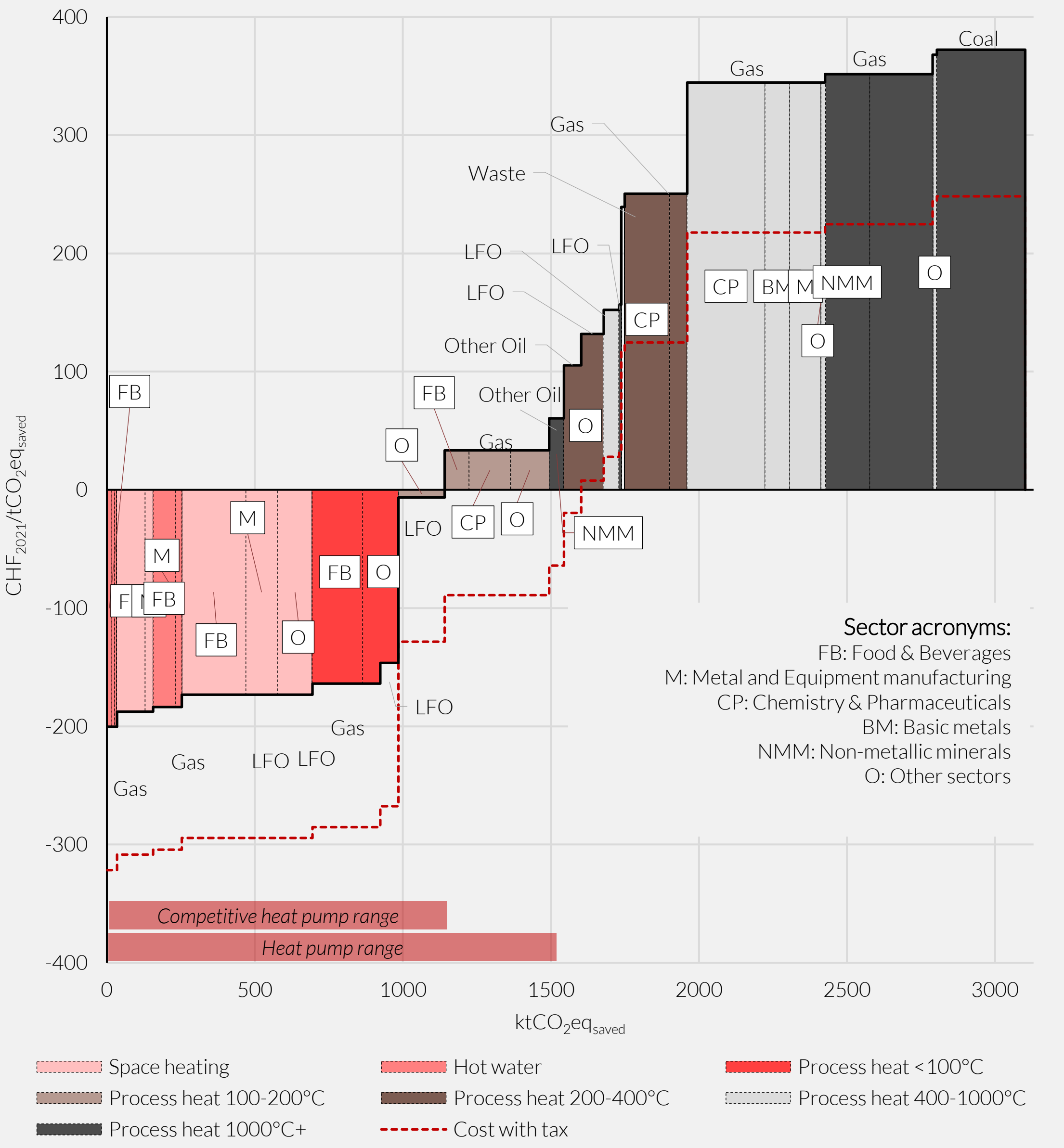
1) Sources: Industrial heat pumps Switzerland, SFOE; Market analysis, E-CUBE Strategy Consultants analysis
2) Hypotheses for energy input costs defined as historical price spreads for industry consumers from FSO: Gas 68-110 CHF/MWh; LFO 58 - 120 CHF/MWh; Wood 70 – 108 CHF/MWh, Electricity 160-170 CHF/MWh

Sources: E-CUBE Strategy Consultants analysis

A significant share of electrification can be profitably achieved with mature technologies, boasting an average abatement cost of -64 CHF/tCO_2eq.

- **Profitable decarbonization:** With current available mature technologies, the cost of emission abatement is at -64 CHF/tCO_2eq and a significant share of electrification can be profitable. This average cost of abatement includes all electrification technologies from stage 1 and stage 2, which are made highly profitable with the inclusion of industrial heat pumps, and their high operating efficiencies. Focusing on energy savings, with all electrification technologies on stage 1 and 2, the average abatement cost of mature technologies is at -19 CHF/MWh saved.

Figure 10: Marginal abatement cost curve[1] for emissions, by fuel switch, sector, and end-use.



1) *Hypotheses for energy input costs defined as average historical price spreads for industry consumers: Gas 68-110 CHF/MWh; LFO 58 - 120 CHF/MWh; Electricity 160-170 CHF/MWh. CO_2 tax is set at 120 CHF/tCO_2eq.*

Sources: E-CUBE Strategy Consultants analysis

- **Specific conditions on profitability:** As highlighted in Figure 10, electrifying non-process heat and process heat <100°C with heat pumps leads to a cumulative potential of 1 $MtCO_2eq$/year with an abatement cost lower than -150 $CHF_{2021}/tCO_2eq_{saved}$. The sectors that benefit the most from these measures, in terms of highest cumulative reduction in emissions, are the Food, Beverages, and Tobacco and Metal and equipment manufacturing sectors, which could see savings of 0.6 $MtCO_2eq$ and 0.2 $MtCO_2eq$, respectively. All other remaining sectors would benefit from a cumulative reduction of 0.2 $MtCO_2eq$ per year. For process heat from 100°C to 200°C, the abatement costs will be largely influenced by the presence of a CO_2 tax; if present, electrifying this end-use would be cost saving. The sectors that would benefit the most from this electrification would be the Food, and Beverages and Chemicals sectors. Moving to higher temperature levels, electrifying would incur additional costs, both with and without a CO_2 tax, as electricity becomes thermally less efficient.

Considering all technologies, the sector's electrification incurs an abatement cost of 102 CHF/tCO_2eq, largely driven by non-mature technologies.

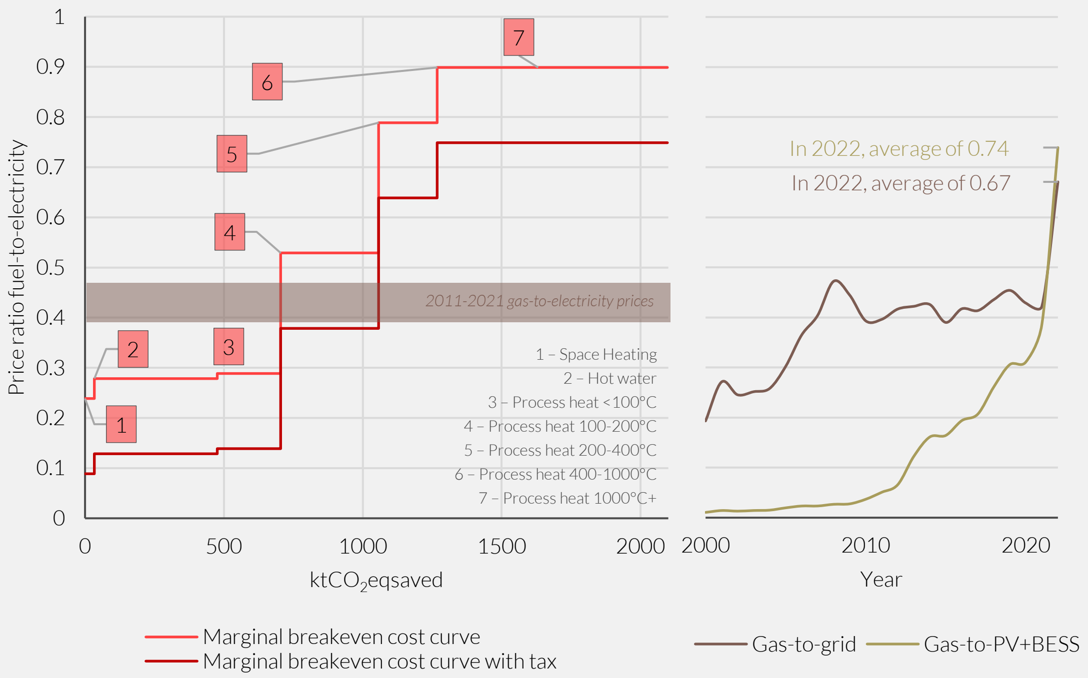
- **An overall electrification comes with costs:** Including the whole portfolio of available electrification technologies to electrify Switzerland's industry integrates technologies that are not mature yet technologically, penalizing their performances, or economically not mature, leading to high financial costs. This concerns stage 3 technologies (>400°C heat demand) which incurs a full electrification cost of 102 CHF/tCO_2eq avoided, equivalently 46 CHF/MWh saved. Increased electrification would require additional efforts to ensure electric technologies remain competitive against fossil alternatives.

- **Fuel-to-electricity price ratios are key for cost-effectiveness:** An examination of the fuel-to-electricity price ratios over the past decade provides essential context, illustrated by Figure 11. Specifically, when fossil boilers are supplanted by heat pumps for non-process heat and for processes necessitating temperatures below 100°C, industrial heat pumps appear economically advantageous. Their breakeven ratio, to become competitive, of 0.26 is notably lower than historical price ratios for LFO (0.36) and gas (0.42). The economics of steam generation through industrial heat pumps are more ambiguous, with breakeven ratios (0.49-0.53) aligning closely with historical benchmarks. Ensuring competitiveness suggests that electricity produced in zones where industries are implemented must be competitive against fossil fuel alternatives. Price ratios not reaching breakeven ratios would lead to a failure in technology switching.

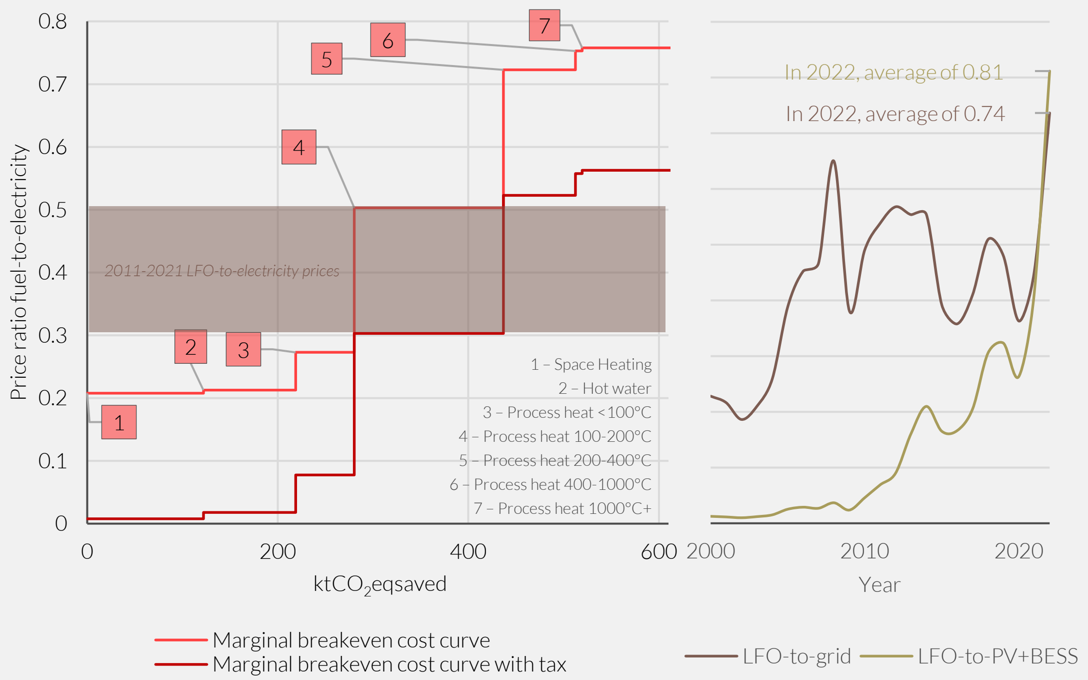
- **Alternative means for competitiveness:** Other efforts such as the introduction of a robust CO_2 tax would shift the economic equilibrium, making such technologies more financially viable as their breakeven ratios would fall beneath historical thresholds. Biomethane, standing as a potential complement to direct electrification in curbing industrial emissions, presents its set of economic considerations. Current economic evaluations of biomethane juxtaposed against PV with battery systems indicate that electrification technologies may be more economically viable up to 400°C. The introduction of a CO_2 tax further accentuates the economic feasibility of electrification across all temperature spectra, as seen on Figure 11.

Figure 11: Marginal breakeven cost curves for electric technologies against selected fossil fuels with their respective historical fuel-to-electricity price ratios

a) Breakeven analysis (with and without CO_2 tax of 120 CHF/tCO_2eq) for electrification technologies (onsite production[1]) and grid electricity) against gas historical price ratios 2000-2022



b) Breakeven analysis (with and without CO_2 tax of 120 CHF/tCO_2eq) for electrification technologies (onsite production[1]) and grid electricity) against LFO historical price ratios 2000-2022



1) Onsite production generation assumed as PV system coupled with Li-ion stationary batteries at an average system cost of ~150 CHF/MWh in 2022. Historical cost data based on battery and PV learning curves.
Sources: SFOE, E-CUBE Strategy Consultants analysis

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Industrial heat pumps are set to be the powerhouse of electrification

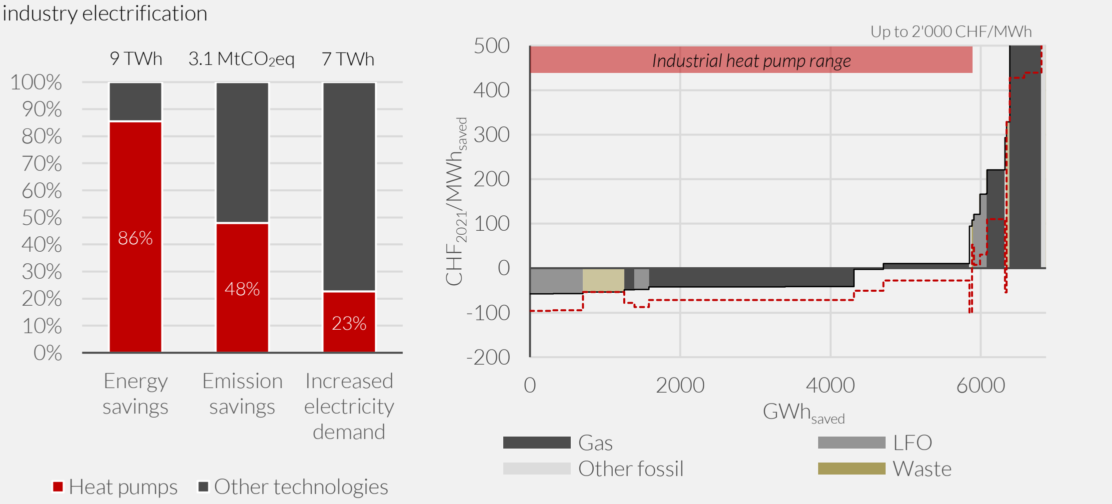
Industrial heat pumps, the backbone of electrification, could profitably save 5.3 TWh of gas and 1.7 TWh of LFO.

- Heat pumps are critical for electrification: A key technology for this scenario is industrial heat pumps, which will lay the foundations for industry electrification, implemented transversally across all sectors to supply heat. They can be competitive against fossil fuel-based boilers for temperature lifts to 80°C and have the potential to reduce 1.5 MtCO2eq from Switzerland's industrial sector, hence over 30% of current energetic emissions. Focusing solely on today's conditions, installing heat pumps could save 5.3 TWh of gas and 1.7 TWh of LFO, respectively 48% and 65% of current consumption. Such savings are accompanied by an increase in electricity demand, of 1.3 and 0.4 TWh, hence only 23% of the increased electricity consumption, while representing 85% of energy savings.

Figure 12: Industrial heat pumps electrification potential in Switzerland's industry

a) Heat pump integration impact share in industry electrification

b) Marginal energy abatement cost curve[1)] by fuel for electrification[2)]



1) The marginal energy abatement cost curve is not shown in full as some electrification technologies reach up to 2'000 CHF/MWh of abatement cost, hence hindering the core message regarding heat pumps. Red dash line shows the same graph without taxes.

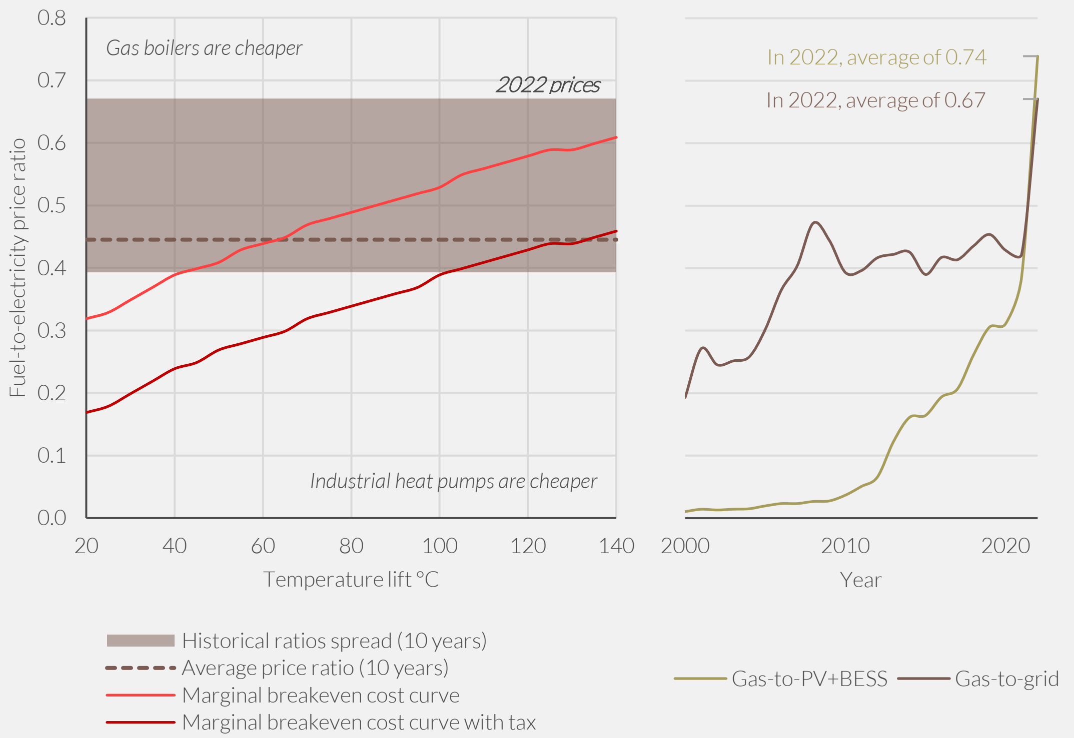
2) Hypotheses for energy input costs defined as average historical price spreads for industry consumers: Gas 68-110 CHF/MWh; LFO 58 - 120 CHF/MWh; Electricity 160-170 CHF/MWh. CO_2 tax is set at 120 CHF/tCO_2eq.

Sources: E-CUBE Strategy Consultants analysis

Cost-competitiveness of industrial heat pumps hinges on fuel-to-electricity price ratios and temperature lift requirements.

- **Heat pumps' competitiveness will depend on the required temperature lifts:** Industrial heat pumps, both within Switzerland and internationally demonstrate economic competitiveness across a range of temperatures and fuel-to-electricity price ratios, especially for processes requiring temperatures below 100°C, upon which any given fuel-to-electricity price ratios render industrial heat pumps competitive against gas boilers. For processes necessitating temperatures between 100-200°C, and hence steam generation, these technologies remain economically feasible up to 60°C temperature lifts given average historical price trends (average of 0.45). However, should fuel prices revert to their decadal lowest point, at approximately 0.39, their economic edge may diminish to a 40°C temperature lift. This underscores the importance of harnessing waste heat as a strategic choice, minimizing requisite temperature lifts. 2022 prices, amid the global energy crisis, led to gas prices extremely high in Switzerland, hence paving the way for industrial heat pumps being competitive regardless of the required temperature lift.

Figure 13: Marginal breakeven cost curves (with and without CO_2 tax of 120 CHF/tCO_2eq) for heat pumps against gas boilers[1)] for process heat 100-200°C (including steam generation) as a function of fuel-to-electricity price ratios[2)] and required temperature lifts.



1) The analysis is only shown for gas boilers as it is the dominant source of heat for steam in Switzerland, LFO boilers are however within the same range of breakeven
2) Onsite production generation assumed as PV system coupled with Li-ion stationary batteries at an average system cost of ~150 CHF/MWh in 2022. Historical cost data based on battery and PV learning curves.
Sources: SFOE, E-CUBE Strategy Consultants analysis

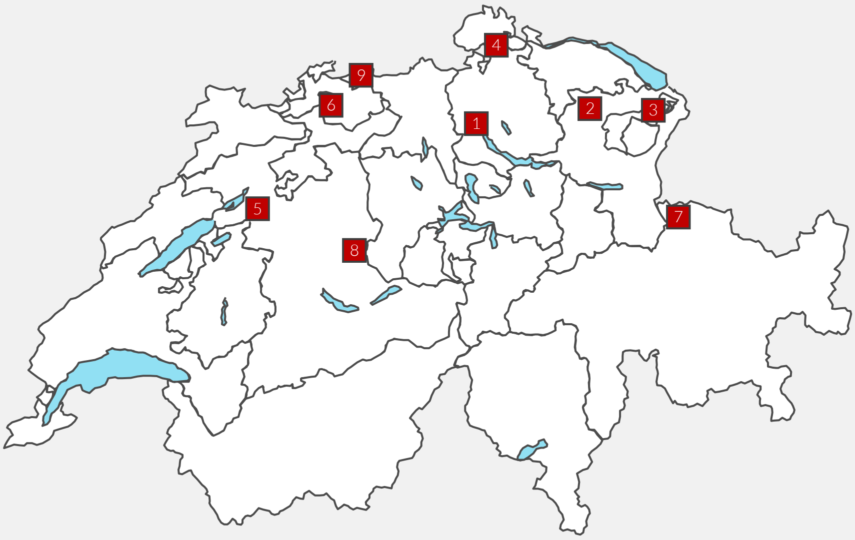
Food, beverages, and tobacco would benefit the most from heat-pumps, by reducing its emissions by 86% profitably.

- Low temperature requirements and homogeneous processes are key for electrification: The most prominent sector, as stated numerous times before is the Food, Beverages, and Tobacco industry. Low temperature requirements (over 80% of heat demand lower than 200°C), and homogeneous processes (cleaning, drying, pasteurization, sterilization, boiling, distillation, hot water, etc.) facilitates the penetration of industrial heat pumps within the sector, hence enabling important cuts in energy consumption (44% reduction), and emissions (86% reduction) at profitable abatement costs of -113 CHF_{2021}/tCO_2eq. As the third highest emitting industrial sector, electrification through heat pumps is key to reach Switzerland's climate goals for this sector.

The industry sector has aligned with heat pump investments, evidenced by case studies since 2009.

- Industrial heat pumps are used since 2009: Contemporary industrial heat pumps have been established in Switzerland since 2009 as pilot projects which delivered significant cost savings, energy efficiency and emission reductions since implementation [10]. Figure 14 illustrates a selection of best practice projects which have been implemented in Switzerland's industry sector whether at the plant level for utility or directly at process integration. Current existing industrial heat pumps only operate at process heat <100°C with maximum temperatures at 95°C, currently no higher temperature projects are implemented.

Figure 14: Selected case studies of industrial heat pumps[1)] in Switzerland



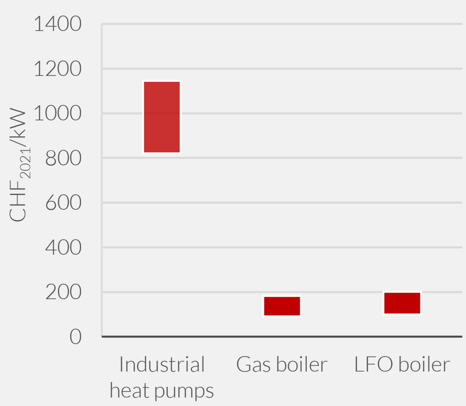
N°	Company	Project year	Sector	Integration level	Application	Impacts
1	Schlachtbetriebe Zürich AG Slaughterhouse	2011	Food & Beverages	Process	Hot water, cleaning	2.6 GWh/y of fossil fuels displaced, 30% reduction in emissions
2	Chocolate factory Maestrani	2019	Food & Beverages	Process	Hot water, heating, cooling	26% reduction in energy consumption, fossil-free production
3	Berg-Käserei Gais cheesemaker	2018	Food & Beverages	Process	Hot water, heating	1.5 GWh fossil gas removed, fossil-free production
4	GVS Schaffhausen Landi	2017	Food & Beverages	Plant	Process/hot water, heating, cooling	40% reduction in emissions
5	Nutrex	2009	Food & Beverages	Process	Fermentation and pasteurization	Fossil-free production, 50'000 CHF/y in cost savings
6	Härterei Gerster AG	2013	Metals	Plant	Process heat for hardening process	80% energy reductions, 800 MWh of fossil gas replaced by 190 MWh of electricity
7	Georg Fischer AG	2010	Machinery	Plant	Heating for production of plastic valves	n.a
8	Kambly SA	2017	Food & Beverages	Process	Hot water for biscuit production	25% energy reduction,90% emission reduction, energy costs reduced by 15%
9	Feldschlösschen	2013	District heating, brewery	Plant	Hot water, district heating	75% reduction in energy costs, 93% reduction in fossil fuels from 12 GWh/an

1) Industrial heat pumps also serve as heat sources for district heating, and are implemented across Switzerland as well, but are not shown in this case as the focus is on industries specifically.
Sources: SFOE, E-CUBE Strategy Consultants analysis

- **Yet challenges hinder the fast deployment of electrification:** Despite cost-competitiveness of electric technologies, several challenges, spanning technical, regulatory, and economic dimensions, hinder the deployment of electrification. A prevailing limitation is most today's projects leaning heavily on tailor-made designs, with high investment costs, which can result in extended payback periods, limiting deployment. Volatility of electricity prices, as seen of figure 15.b), met with increasing penetration of renewables and an increased demand from electrification, adds another layer of stakes regarding competitiveness of electricity prices against alternatives. From a technical perspective, a significant knowledge gap persists regarding the technical prowess and viable economic applications of electrification technologies, such as industrial heat pumps, exacerbated by the lack of Industry Best Practices and significant available commercial case studies. Finally, electrification requiring process changes hinders deployment as lack of production for industrial stakeholders from long projects, penalizing their economics. Focusing specifically on industrial heat pumps, finding suitable cold sources with is also key for increased electrification, as lack of environmental potential may hinder deployment or maximised temperature outputs, heat waste recovery through heat pumps is set to be key for their deployment.

Figure 15: Financial parameters hindering electrification.

a) Specific investment costs[1)] of heating technologies in Switzerland, 2021



b) Electricity prices on the "Day Ahead" spot market Swiss base, 2019-2023

1) Investment costs for heat pumps covering 100-200°C process heat (incl. steam generation) are not listed here as they are not present in the Swiss market. Investment costs cover equipment cost as well as installation costs.
Sources: SFOE, EPEX SPOT, E-CUBE Strategy Consultants analysis

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