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# Working Paper

## Industrial Transformation for Decarbonisation: Stakeholder Perspectives on Economic and Systemic Barriers to Electrification

Oeko-Institut Working Paper 5/2025

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## Abstract

Empirical results from interviews and the literature on industrial decarbonisation support findings on transformation: industrial transformation through electrification is a complex multi-level problem. Companies are facing barriers on many different levels. This underlines the important role that the state has to play in coordinating a policy mix that solves these problems. However, industrial transformation through electrification poses high demands on policy-making. A policy package is needed that addresses a combination of different barriers that the industry is facing: high electricity prices, insufficient infrastructure and unattractive investment conditions among others.

Chapter 4 provides an overview of the barriers that were identified through this paper's research. They were grouped in the following categories:

- Operating costs of electricity-based process heat technologies.
- Energy system factors that hinder the uptake of electricity-based process heat technologies
- Capabilities of businesses to invest in electricity-based process heat technologies.

Stakeholders highlighted that the operating costs of electrification technologies are the main hurdle for the application of electrification technologies, see chapter 4.1. Electricity prices and its components have a significant impact on the decision to invest in electrification technologies. Especially in 2022 – during which energy prices were very high – stakeholders pointed out the importance of driving electricity prices down. The level of these prices depends on the market price as well as state-induced price components, such as grid fees or taxes.

To drive down electricity prices, different policies are needed, which address the different problems on their respective levels. Especially measures that lower the electricity prices and make electricity-based technologies economically feasible in the face of prevailing gas prices are very important. Stakeholders also stressed the importance of planning security with regard to electricity prices, which is needed to engage in a technological change towards electrification. In 2024 different measures that were categorised as important by the stakeholders were implemented: The reduction of the electricity tax to the European minimum and the introduction of carbon contracts for difference. Some stakeholders questioned whether the current market design is able to reflect the low generation costs of renewable electricity. However, they were not able to point out how the design should be further developed.

Stakeholders also pointed out different barriers on a systemic level, see chapter 4.2. In particular, the availability of sufficient renewable electricity and grid capacity were categorised as highly relevant. On the level of single industrial sites, electrification goes hand in hand with increased grid capacity needs, which means that the expansion of the site's grid connection is necessary if electrification is to be realised. Depending on where the site is situated, this is not necessarily possible as the next grid connection point of a higher level is too far away or a higher grid has insufficient capacity.

Stakeholders pointed out that for higher temperature levels, no technologies exist to date that fulfil the needs of industrial companies. Research and development is therefore deemed very important to increase the energy efficiency of these technologies and their ability to flexibly alter the temperature they provide.

This shows the high importance that stakeholders assigned to the infrastructure and technologies needed for the electrification of the industry. Renewable electricity and its transportation on the supply side as well as electrification technologies that can meet the industry's needs on the

demand side are the basis for electrification. From a policy maker point of view, this highlights how important it is to continue renewable expansion and the expansion of the transmission and distribution grid alike and also support further technological development of high temperature electrification technologies.

When deciding on an investment, both operating costs and investments costs are important. However, in this field fewer relevant barriers were specified by stakeholders, see chapter 4.3. Higher investment costs and long amortisation times were described as problematic. Conventional technologies show lower investment costs and shorter amortisation times, which is especially important in the light of financial reporting to the advisory board. This problem needs to be addressed as the logic of investments and return on these investment needs to change. Policies that support investment can help to overcome these barriers. However, in the long run investments should be realised without governmental support.

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# 1 Introduction

This report deals with barriers to the electrification of German industry as one element of broader industrial transformation.

Climate policy is increasingly focusing on industrial transformation. While the main policy focus for reducing greenhouse gas (GHG) emissions has been the energy sector to date, this is about to change. In the energy sector and especially power production, renewable energy technologies have undergone major innovations, cost reduction and increasing deployment rates. This has been the main driver of decreasing greenhouse gas emissions in this sector.

As a result of this development, the German industry sector is expected to overtake the energy sector in terms of GHG emissions in the years ahead and to become the sector with the highest emissions (UBA 2024). This highlights the need to address decarbonisation in this sector and what hinders the implementation of decarbonisation options.

This report focuses on one of these options: electrification. Other options include indirect electrification via hydrogen or the reduction of energy demand. In any case, as in any sector, decarbonisation of industry requires a stronger integration with the power sector. However, decarbonisation of the power sector is not sufficient; major structural changes in the industry are also required.

At the same time, industry is also facing many other challenges and transformations beyond climate policy. There can be synergies, but transformation can also lead to unsustainable solutions. International competitiveness needs to be maintained or increased and other mega-trends like digitalisation also entail structural transformations. Electrification of German industry to meet climate targets is one potential pathway and needs to be aligned with other developments. Beyond greening the industry in Germany, there can be destructive pathways, and one alternative pathway may be a shift of industry to other countries.

While the focus of this report is on barriers to electrification in the German industry, this specific development is embedded in a broader system transformation.

Therefore, section 2 offers a brief overview of this transformation perspective and goes on to introduce industrial transformation through electrification. Section 3 explains the methodology that was applied for the empirical part. Section 4 presents the results of the barrier analysis, which are then summarised in section 5. A conclusion is provided in section 6.

# 2 System transformation and the need for industrial transformation

## 2.1 System transformation: overview

The need for a transformation stems from the far-reaching environmental impact of human activity (Klaus et al. 2020). Many of the planetary boundaries that were defined by Rockström et al. (2009) are exceeded, which threatens the very basis of humanity. Although there have been successful environmental policies, the root of the problem lies deeper: it is of systemic nature. Unsustainable production and consumption can only be corrected through a systemic change or system transformation towards sustainability (Klaus et al. 2020).

Wolff et al. (2018) describe that in the past transformation has been typically accompanied by increasing environmental burdens, rather than providing solutions to existing environmental problems. Transformations were merely planned, but occurred as a result of human actions. Examples are the replacement of wood by coal and later oil and natural gas in the energy sector or the transition from feudal agrarian societies to capitalist industrial society. Moreover, transformations are of a conflictual character and thereby create resistance as new actors emerge and question existing power equilibria (Johnstone and Kivimaa 2017).

Compared to past transformations, it is clear that a necessary sustainable transformation is fundamentally different. It aims to reorganise and restructure the current system. Due to the complexity of this change and perceived conflicts between stakeholders, an active state that governs this change seems indispensable as only the state possesses the ability to address these transformational challenges on multiple levels. However, some actors doubt that states possess sufficient capabilities to address these problems (Kronsell and Bäckstrand 2017; Mazzucato 2013). Nonetheless, a sustainable transformation is deemed necessary from a political point of view and found its way into corresponding international and national policy discussions.

Examples of transformation in policy can be found on international and national levels alike. In its Agenda 2030, the United Nations (2015) has formulated seventeen Sustainable Development Goals (SDGs) to guide the direction of transformation. In Germany, the Sustainability Strategy (Die Bundesregierung 2021) implements the SDGs at national level and describes deep-rooted systemic transformation as the basis for a sustainable future. One of the SDGs comprises a resilient infrastructure, an inclusive and sustainable industrialisation and innovation (United Nations 2015), directly addressing the unsustainable practices in the industrial sector.

BMWK (n.d.) highlight that industrial activity made up almost a quarter of German greenhouse gas emissions in 2021. This share will continue to increase in the future as emissions from the electricity sector decline in line with the expansion path for renewables set out in the German Renewable Energy Sources Act (EEG) [1]. The steel, cement and chemical industry pose the largest pollutants in this sector. Due to the goals defined in the German Climate Action Act (KSG) [2], the industrial sectors must undergo a transformation that is based on decarbonization, electrification and circular economy.

Sachverständigenrat für Umweltfragen (2016) describe the state's role in shaping transformations. Transformations are polycentric and shaped of multiple change processes that take place at the same time. This creates an increasing need for coordination of transformation to somehow steer

1 Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz) of 21 July 2014 (Federal Law Gazette I p. 1066), last amended by Article 1 of the Act of 21 February 2025 (Federal Law Gazette 2025 I No. 52).

2 Federal Climate Action Act of 12 December 2019 (Federal Law Gazette I, p. 2513), last amended by Article 1 of the Act of 15 July 2024 (Federal Law Gazette I No. 235)

these parallel developments in a sustainable way. The coordination of these processes is challenging as they need to be addressed individually in their respective sphere, e.g. consumption, production, culture, etc. This leads to a paradoxical situation in which the need for and the inability of governance co-exist. Kronsell and Bäckstrand (2017) also came to this conclusion; however, they point out that only the state has the authority and power to orchestrate a collective response to complex environmental problems. Grießhammer and Brohmann (2015) describe how the state can take an active role in shaping a transformation. However, they also add that the polycentric character of transformations makes it barely possible to control it in its entirety. They stress that the state's ability to support innovations are especially important after an innovation has been developed by 'pioneers of change' and is ready-for-use and its widespread application can be supported.

Sachverständigenrat für Umweltfragen (2016) acknowledge the complexity of transformations but add that the state can play different roles in all of its stages. They describe the transformation process, which begins with a niche phase in which innovations are developed, a transition phase in which innovations are introduced to an existing system, and finally the new system phase in which a new equilibrium is reached.

In the niche phase, the state can create room for experiments and support innovations. The state takes on an enabler role in the transition phase, enhancing structural change and gathering policy feedback. Finally, the state supports a new equilibrium by creating a stable framework. Hence, enabling innovations is not enough for successful transformations. It is necessary to reduce barriers and inhibiting structures. Alongside policy support of technological change, support of structural changes and possible social effects is also necessary. An example of this is the German coal phase-out (SRU 2015).

Industrial transformation is a crucial part of decarbonisation as industrial carbon dioxide emissions comprised around a quarter of global emissions in 2022. Given that the emissions of the energy sector are decreasing, the industrial sector will become more important in this regard in the future. Today the sector is dominated by fossil fuel consumption and technological innovation and technology deployment rates need to be accelerated. More importantly, do national policies not seem to be sufficient to get industrial activities on track with climate protection (International Energy Agency 2024).

Different conceptual frameworks can be applied to explain how industrial activity can be decarbonised. Sovacool, Benjamin, K. et al. (2023) conducted a broad literature review of approximately 500 papers on conceptual frameworks on industrial societal change in a low carbon future. They found 88 models of decarbonisation, which were narrowed down to eight different conceptual families. This stresses the complexity of industrial decarbonisation which can be addressed on many different levels. Models explore industrial decarbonisation from a sociotechnical perspective, with regard to organisational behaviour or industrial ecology and sociology among others.

In the scope of this paper, models regarding the politics of governance and innovation and its diffusion are particularly relevant. They explain how policy and governance influence innovation in industry and the uptake of innovative technologies.

Johnstone and Kivimaa (2017) reflect on policy change and disruption in their article. They highlight that green industrial policy is important to manage systemic disruptive effects of low carbon transitions. They argue that disruption can extend beyond technology to regulation and other institutional settings (Johnstone et al. 2017) and thereby comprise the introduction of regulatory frameworks that allow the widespread application of innovations. This can be compared to the earlier understanding of the state's role in transformation and the management of possible social effects (Sachverständigenrat für Umweltfragen 2016). This seems especially important for energy-related transformations as these entail systemic changes that extend to traditional industries: Not only the ways in which energy is generated change, but also the ways in which energy is consumed and marketed. Therefore, policies should also address possible negative impacts of technological disruption to protect jobs and livelihoods (Johnstone and Kivimaa 2017).

Hildingsson et al. (2018) highlight the important role of the state in industrial decarbonisation. They highlight that regulatory interventions are necessary as market-driven change is not sufficient to meet climate targets. One reason for this is the privileged position of the industry as for a long time economic growth was and to a large extent still is based on the exploitation of natural resources through industrial activity. Mazzucato (2015) highlights the importance of an active state in enabling a sustainable transformation. They find that in states that are global leaders in green transition, the state has an active role in steering capital to most innovative and risky parts of the green economy. A number of capital-intensive radical innovations can be traced back to the state, such as railroads and pharmaceuticals. In this way, the state assumes the role of an enabler, helping to bridge uncertainties and willing to take financing risks that businesses will not. A practical example of this is the introduction of the feed-in-tariff scheme for renewable energies in Germany. Yang and Umair (2024) also find the positive impact of green industrial policy on green innovations. They conducted an econometric analysis of different Chinese provinces that differentiate from each other by their industrial policy and level of pollution. They find that the impact varies by degree of pollution, highlighting the importance of policies that consider regional differences.

Therefore, it can be concluded that as the decarbonisation of the industry poses a complex undertaking, state actors have an important role to play. They need to design a policy framework that enables innovations, structural change and carries industrial activity to a new sustainable equilibrium. However, to understand how the regulatory or policy framework needs to be designed, it is necessary to review what currently hinders industrial transformation. The stakeholder interviews conducted for this paper help us to understand what needs to be addressed politically to support industrial transformation.

## 2.2 Industrial transformation through electrification

With its Climate Action Act, Germany has set the goal of achieving climate neutrality by 2045 (Bundesministerium für Wirtschaft und Klimaschutz 2024). Meeting this decarbonisation goal also means a reduction to net zero by 2045 for the industrial sector. This places high demands on the sector, which has seen little reduction in emissions in recent years (Umweltbundesamt 2022).

Industrial emissions can be divided into combustion emissions, which result from the use of fossil fuels to generate heat and electricity and process emissions, which are non-energy related by-products of manufacturing processes. In 2022, combustion-related emission made up roughly two thirds of industrial emissions, amounting to 116.4 million t $CO_2$ equivalents (Hermann and Emele 2023). This is also reflected in the primary energy used for heat generation in German industry in 2020: only 16% of process heat was generated with electricity in 2020. In contrast, 65% was generated by natural gas, coal and oil (Agora Industrie 2022). This highlights the high relevance of reducing the use of fossil fuels and the related emissions to meet the climate goals of the Climate Action Act.

Reducing emissions from combustion can be realised by means of different approaches, which entail far-reaching technological changes. According to Bruyn et al. (2020), they comprise

- the increase of energy efficiency

- the application of new heat generation technologies, such as power-to-heat or deep geothermal heat generation, or
- the substitution of fossil fuels with renewable ones, such as biomass or green hydrogen, in which case the use of the conventional combustion technology continues.

In a study for the Federation of German Industries the BCG (2021) highlighted the high relevance of a shift towards electricity-based technologies and a switch from fossil fuels to renewable electricity. In a more recent study, published in 2024, Fraunhofer ISI (2024) found that technologies that are currently available could already decarbonise 60% of energy demand that has not yet been electrified. With technological progress, 90% decarbonisation is possible by 2035. This is a finding that is similar to those published in 2020 by Madeddu et al. (2020), who found that 78% of energy demand could be covered by  technologies that are already available and 99% with technologies under development.

The electricity-based technologies that are already available can comprise a potent decarbonsiation strategy if renewable electricity is used. However, these technologies are hardly applied in practice (Agora Industrie 2022), which gives rise to the question: What are the reasons hindering companies in applying electricity-based technologies? Reviewing the literature on barriers to electrification shows that they vary between industrial sectors and countries:

Fraunhofer ISI (2024) and Bruyn et al. (2020) analysed the European situation, while Mallapragada et al. (2023), Wei et al. (2019) and Deason et al. (2018) focus on the situation in the US. Fraunhofer ISI (2024) conducted interviews with European businesses and manufacturers and found technical, economic and organisational barriers. Bruyn et al. (2020) found that unattractive business cases, an insufficient infrastructure and technological state of electrification technologies hinder emission reduction in European industry. Other work such as Mallapragada et al. (2023), Wei et al. (2019) and Deason et al. (2018) analyse barriers that come about in the US and highlight that economic barriers hinder electrification. This underlines the high complexity of industrial electrification. Barriers to the application of these new technologies are found on different levels and are not only a question of economic feasibility.

The literature also shows that electrification is a challenge that differs between sectors: Jannasch et al. (2020) analyse the Swedish chemical industry, Salamone et al. (2020) focuses on the Swedish cement industry and Mallapragada et al. (2023) analyse the chemical industry. Richardson-Barlow et al. (2022) analyse the decarbonisation of the steel sector in the UK and Kim et al. (2022) analyse the decarbonisation of iron and steel industry without a national context or technological focus. These papers show that the ways in which electrification will be realised in different sectors differ due the very different production processes. In the steel sector, electrification will mostly be applied to melt scrap steel. Primary steel needs to be reduced by applying hydrogen. In the chemical sector, electricity is possible through the application of steam crackers. Different technological approaches face different challenges.

Only a small share of studies deal with the German situation. IN4climate.NRW (2022) published a short impulse paper on the topic of the decarbonisation of process heat in Germany. Agora Industrie (2018) analyses possibilities of decarbonising the steel, chemical and cement industry. In a more recent study Agora Industrie (2022) takes a more detailed look at the topic of process heat decarbonisation through electrification and identifies barriers to companies in Germany. In a recent study, Fraunhofer ISI (2024) analyses the potentials and barriers to electricification.

This paper focuses on barriers to electrification in the German industry. This contributes to the current research conducted in this region and provides up-to-date insights into the situation in the

German industry. We chose a broad sectoral focus of the sectors steel, chemical, cement industry as these sectors emit the majority of industrial emissions (Hermann and Emele 2023).

# 3 Methodology

The results of this paper stem from a literature review and from stakeholder interviews. In the following section, the methodology for these two parts is explained. The research was conducted in two steps. First literature regarding industrial electrification and decarbonisation was viewed to gain an understanding of which barriers can hamper the application of electricity-based technologies. Based on this understanding, the interview guidelines were formulated for stakeholder interviews regarding the German situation. The results of the literature review and the interviews are presented jointly in chapter 4.

This paper is exploratory. Therefore, we chose not to focus our work on a single industrial sector. Rather, we aimed to identify the barriers and topics that are relevant to the industry as a whole.

## 3.1 Literature review

The aim of the literature research was to gather barriers to the electrification of industrial companies that are currently documented in journal articles. We viewed articles from relevant journals such as Energy Policy[3] or Journal of Cleaner Production[4] as well as grey literature. The findings were relevant to developing interview guidelines and to place the empirical findings into context. As this paper is not wholly based on a comprehensive literature review, we only considered as many references as were necessary to gather an understanding of the current situation with a view to the application of electricity-based technologies and to formulating the interview guidelines.

The work presented in this paper takes a broad perspective on industrial electrification. Therefore, literature was considered that addressed industrial decarbonisation without a sectoral focus. We also widened the geographical focus beyond Germany so as to identify barriers that appear in other countries which could also be considered relevant in Germany. Particularly relevant were papers that collected empirical findings on barriers to electrification through primary data collection.

The research focused on literature with the following keywords and/or their combinations: electrification, power-to-heat / power-to-x, technical change, transformation, companies, industry, obstacles, barriers.

## 3.2 Semi-structured interviews with experts

To gather information from stakeholders, we conducted semi-structured interviews (SSI) on the topic of barriers to industrial electrification. According to Adams (2015), SSIs are a qualitative methodological approach that lies between standardised surveys and open group discussions in order to collect data. It combines elements of the two previous approaches to create a new method. SSIs use a mixture of closed and open questions when interviewing individual participants. The dialogue of the interview can also deviate from the interview questions and drift into unplanned areas. They usually last around an hour.

Due to the amount of preparation and follow-up work involved, it is only possible to interview a small group of stakeholders. However, asking open questions allows stakeholders to give very detailed answers. Due to the individual setting, they are more open to giving answers that they might not offer in a workshop or plenary session (idb.).

3 See https://www.sciencedirect.com/journal/energy-policy (last accessed on 09.03.2023).
4 See https://www.sciencedirect.com/journal/journal-of-cleaner-production (last accessed on 09.03.2023).

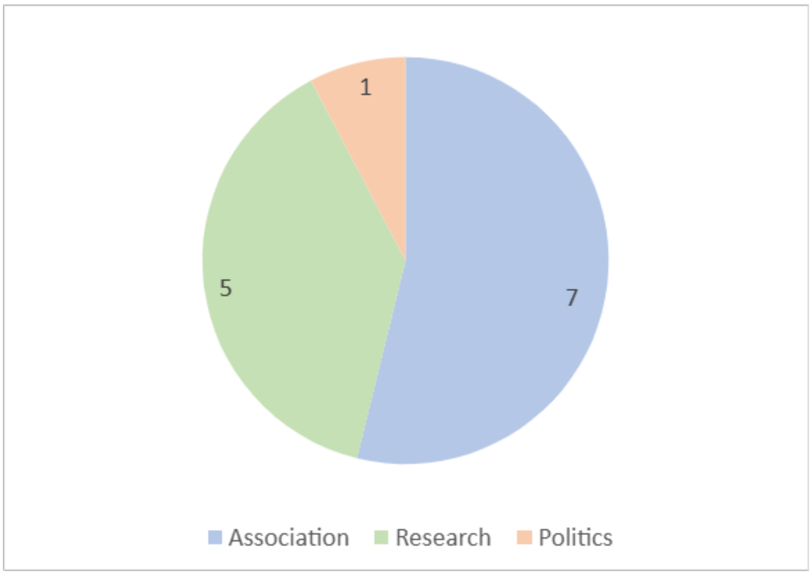
Based on the literature research, we developed interview guidelines that consisted of a combination of closed and open questions. On the one hand, the closed-ended questions are intended to explore the findings found in the literature, while the open-ended questions offer scope for sharing further experiences in relation to the current situation. In addition, stakeholders were asked about the relevance of barriers.

Thirteen interviews were conducted in the scope of this paper. The goal of the stakeholder selection was to interview stakeholders with different points of view on the topic of industrial decarbonisation through electrification overall. Industrial interest groups have practical insights into businesses and can describe what the factors hinder the electrification of industrial processes. However, as they work for interest groups, the neutrality of their information must be questioned. It has to be considered that these stakeholders need to ensure the economical feasibility of companies associated with their interest groups. Also, these interest groups have a sectoral focus as they represent a single industrial sector, such as cement, steel or chemicals. We did not dig more deeply into the barriers that are particularly relevant for these sectors, but concluded through comparison between the interview results which barriers are of relevance for industrial decarbonization independent from their respective sector.

Additionally, it was essential to interview stakeholders that are not bound to economic interests and reflect on the topic of industrial decarbonisation from a more systemic perspective. For this reason, interviews were conducted with research organisations that work on the topic of industrial decarbonisation. These institutions were chosen because they traditionally represent a systemic view of systemic decarbonisation, complementing the view of industrial interest groups.

In the following figure, the different types of stakeholders and the respective number of stakeholders interviewed are depicted. Four stakeholders worked at research institutions, six stakeholders worked for industrial interest groups and a single stakeholder worked for a political decision maker. The interviews were evaluated anonymously, and each interviewee was given a number under which they are cited in this paper.

**Figure 3-1: Overview of interviewed stakeholders by type**




Source: Authors' own depiction

## 3.3 Evaluation of barriers and their severity

After the interviews were conducted, they were evaluated. Firstly, the interviews were evaluated with a view to the barriers specified overall. This comprises barriers specified in the literature and new barriers that had not yet been mentioned. The barriers were then grouped into three different categories. These were:

- operating costs of electricity-based process heat technologies;
- capabilities of businesses to invest in electricity-based process heat technologies; and
- energy system factors that hinder the uptake of electricity-based process heat technologies.

In a second step, the severity of the barriers was evaluated. Stakeholders were asked how strong they deemed the barrier to be. Depending on their answer, barriers were divided into the following three groups:

- **Severe:** The majority of stakeholders specified this as a barrier which is central to the decarbonisation based on electricity-based technologies The majority of stakeholders described this barrier as central and there were no statements rejecting this.
- **Important**: Not every stakeholder named this barrier and there were also stakeholders who did not agree on the effect of this barrier.
- **Only relevant in single cases:** Only single stakeholders described this barrier as relevant, with the majority of stakeholders either not mentioning it or rejecting it.

# 4 Barriers to the electrification of German industry

The transformation of industry towards carbon neutrality is one part of system transformation. Without the transformation of this sub-system, it will hardly be possible to achieve Germany's climate targets as it makes up a considerable share of the overall emissions, see above. Electrification of industrial processes is one possible transformation path the industry can take to substitute fossil fuels with emission-free electricity and thus reduce process emissions (BCG 2021).

The interviews were conducted in 2022. In this year, the industrial sector was in the midst of the energy crisis brought about by the Russian war in Ukraine. Consumers and companies faced extremely high energy prices during 2022 and 2023. The results of the interviews of this study should be seen in the light of these circumstances.

This section jointly presents the results of the literature review and the stakeholder interviews. They show that different barriers to electrification exist. These can be grouped into the following categories:

- **operating costs** of electricity-based process heat technologies.
- **energy system factors** that hinder the uptake of electricity-based process heat technologies.
- **capabilities** of businesses **to invest** in electricity-based process heat technologies.

An overview of all barriers identified in the research conducted for this paper can be seen in the following figure. Nine of 15 barriers belonged to the category of operating costs; three barriers to the category of investment capabilities and four barriers to the category of systemic factors.

The different barriers differ in their relevance, as shown by the colours. Red and '—' shows that the barrier was described as severe with a view to the implementation of electricity-based technologies. The majority of stakeholders described this barrier as central and there were no statements rejecting this notion. Orange in combination with '-' shows that this barrier was acknowledged as important; however, not every stakeholder named this barrier and also stakeholders did not agree on the effect of this barrier. Yellow in combination with '(-)' describes that only single stakeholders described these barriers as relevant, with the majority of stakeholders either not mentioning it or rejecting its relevance.

**Figure 4-1: Overview of barriers by category and their relevance**

| Operating cost of electricity-based process heat technologies | | Energy system factors that hinder the uptake of electricity-based process heat technologies | | Capabilities of businesses to invest in electricity-based process heat technologies | |
|---|---|---|---|---|---|
| High electricity prices | -- | Availability of renewable energies | -- | High investment costs and long ammortisation time | - |
| Electricity market design | - | Limited technology readiness level | - | Maximization of financial benefits | (-) |
| State induced price components | (-) | Limited capacity of grid connection | - | Availability of external capital for investments | (-) |
| Grid fees | - | Long permitting procedures | (-) | | |
| capacity price | - | | | | |
| §19 (2) of the Electricity Grid Charges Ordinance | - | | | | |
| EU ETS | (-) | | | | |
| low and volatile certificate prices | (-) | | | | |
| free allocation of certificates | (-) | | | | |

-- severe  - important  (-) only relevant in single cases

Source: Authors' own depiction

Figure 4-1 shows that barriers deemed to be the most severe were high electricity prices and the availability of renewable energies. Other barriers were either deemed important or only relevant in single cases. The category of operating costs comprises the highest number of severe or important barriers. The category of energy system factors consists of one severe barrier, two important barriers and a single barrier that is only relevant in single cases. The category of investment capabilities only comprises of three barriers, of which only one is deemed important and two were considered only relevant in single cases.

It follows from this that stakeholders consider barriers in the field of operating costs as the strongest ones. Nonetheless, barriers in the scope of energy system factors can also be a so-called 'show stopper' for electrification. From the interview results, it follows that barriers in the field of investment capabilities are not as relevant as other barriers.

The presence of barriers can be seen as critical in the light of the necessity of the industry to decarbonise. Policy targets and the EU Emission Trading System put pressure on companies to reduce their emissions. However, as a result of these barriers, it becomes harder to implement carbon-neutral technologies and reduce emissions. This creates the necessity, from a political point of view, to address these barriers and foster industrial electrification.

In the following chapter, the results of the literature review and stakeholder interviews are jointly presented. The findings for each barrier mentioned in the course of the interviews are presented in the following sub-chapters.

## 4.1 Operating costs of electricity-based process heat technologies

When investing in and using a technology, not only the investment costs, but also the operating costs are relevant. A technical switch to electricity-based technologies will only be realised, if they result in lower total costs than their fossil alternatives. From both literature and interviews, it becomes clear that the operating costs of electrification technologies comprise a strong barrier to electrification.

### High electricity prices and operating costs

Results from the literature review show that operating costs of process heat technologies are crucial for investment decisions. Wei et al. (2019) point out that in the US, fossil technologies often have lower operating costs and are therefore more attractive to companies. They point to the discrepancy between the costs of electricity and gas, with gas being cheaper than electricity in most cases. Deason et al. (2018) also stress that although electricity-based technologies are often economically viable, US electricity prices are too high, making the application of electrification technologies unattractive. Jannasch et al. (2020) point out that not only the current electricity prices are important to making an investment decision. Also, insecurity about the availability of cost-efficient, green electricity can hinder companies in choosing electrification. van Geem and Weckhuysen (2021) also identified the same barrier in the European context; the barrier was also stressed by Agora Industrie (2022) and Agora Industrie (2018) for Germany.

Also, different industrial position papers stress the importance of economically available green electricity. The German industrial interest groups for steel, chemistry and cement emphasise the important relevance of low energy costs in position papers (VCI 2021; VDZ 2022; WV Stahl 2021), which was also put forward by the German Council of Economic Experts, which stated that *'measures that ensure low costs for these energy sources in the long term [will] be of paramount importance for the industry'*[5] (Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung 2022, p. 263).

As results from literature regarding the important role of operating costs was very strong, similar findings were expected from the interviews. Almost all stakeholders rated high electricity costs as the largest obstacle to electrification [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]. Without low electricity prices that make electricity-based technologies economically viable in the face of prevailing gas prices, electrification is difficult to realise. Electricity as the central energy source for decarbonisation must be offered as cheaply as possible compared to gas [6,10]. Low gas prices for years prevented the development of other options [6]. Low electricity prices are particularly relevant for companies in international competition as the switch to electricity-based processes is only possible with difficulty if European electricity costs greatly exceed those of other regions of the world [1, 2, 10].

### Electricity market design

Stakeholders specified the current electricity market design as one reason for high electricity prices. Due to the applied uniform pricing, the low costs of renewable power plants are not reflected in the market's clearing price [9]. When the clearing price is set by gas power plants, the electricity price is coupled to the gas price (Zachmann et al. 2023). During these times, the electricity price per kWh will be always higher than the gas price due to the efficiency losses of gas power plants. This also became clear in the energy crisis of 2022. In that year, gas prices sharply rose which also led to very high electricity prices.

[5] Translated by the authors.

One stakeholder [9] points out that this timely coupling of energy carrier prices prevents that electricity prices drop below gas prices, which is needed to motivate companies to switch between technologies [1, 9]. As a result, a stakeholder considered the revision of the market design to be inevitable, as high prices would otherwise pose a threat to the industry, electrification and decarbonisation [9]. However, the stakeholder did not specify what form this revision should take. One stakeholder [12] suggested the introduction of a price cap to protect consumers from a sharp price increase. Similar mechanisms were realised for households in Germany with the so-called energy price brake. Stakeholders [3, 5, 10] also stated that the current market design could not provide planning security regarding low electricity prices. Companies do not assume a constant price development that would enable investments.

With an increase of renewable generation and demand-side flexibility, it can be expected that consumers will exploit times of low electricity prices. This gives rise to the question of whether the current market design really needs to be revised and what the alternative to the current market design would be.

Based on how the stakeholders evaluated it, the current market design can be categorised as an important barrier to electrification. The main critique focuses on the coupling of electricity and gas price. However, it remains to be seen whether this barrier will continue to be highly relevant.

**State-induced price components**

When analysing the reasons for high electricity prices, it becomes clear that for large industrial consumers, the cost of electricity itself is the main cost driving factor. When looking at the composition of the industrial electricity price, there are hardly any price components for which an exemption or price reduction cannot be applied (bdew 2024). The most important components are:

- Cogeneration levy (exemption possible)
- Levy for reduced electricity grid fees for energy intensive consumers as defined by §19 (2) of the German Electricity Grid Charge Ordinance
- Offshore grid levy (exemption possible)
- Electricity tax (reduced to European minimum for manufacturing industry from 2024 onwards)
- Grid fees (exemption possible, discussed in detail later in this chapter)

From this, it follows that for industrial electricity prices and the way electricity prices form in the electricity wholesale market is especially relevant, see above.

The limited role that other price components play was also expressed by stakeholders. One stakeholder [1] stated that in 2022 only the electricity tax was a relevant component as for other components exemptions exist. Another stakeholder [7] added that electricity price components are hardly relevant as they are not raised on self-consumption, which was stated to be a major source of industrial energy supply.

Other stakeholders [10, 11, 13] expressed that the electricity tax was deemed relevant and needs to be reduced to the European minimum. Moreover, compared to the gas price, electricity is in a worse position, as state-induced price components that are raised on the gas price do not result in sufficiently high prices for a technological switch. A stakeholder stressed that this is relevant especially for smaller consumers who do not qualify for exemptions [12]. However, for industrial consumers, this has little relevance. For these consumers, the costs of electricity generation itself

have the highest relevance.
Based on these stakeholder opinions state-induced price components can be classified as of low relevance. Research that focusses on the electrification of small-scale businesses would come to a different conclusion, as exemptions for price components often do not apply to these consumers.

After the interviews were conducted in 2022, a new regulation was implemented that, from 2024 onwards, reduced the electricity tax to the lowest tax rate of 0,05 cent/kWh for the manufacturing industry in the scope of the German Electricity Price Package (Die Bundesregierung 2024).

It has to be made clear that smaller consumers do face price components that increase the electricity price. This can also be a barrier to electrification (IN4climate.NRW 2021).

**Grid fees**

In Germany, the regulation on grid fees for large energy intensive consumers is highly relevant for industrial companies as it grants a large discount and is based on §19 (2) of the German Electricity Network Charges Ordinance (StromNEV 2023). This regulation offers a discount to companies that either draw large amounts of electricity smoothly from the grid or limit their consumption to fixed time windows. The discount ranges from 80% to 90% of the grid fees.

In the literature this regulation is often discussed as a barrier to demand flexibilisation, see e.g. Frank et al. (2022), IN4climate.NRW (2022) and Grosse et al. (2020). In this regard, the regulator, the German Federal Network Agency, is revising this regulation in 2025 to incentivise a flexible energy consumption by industrial consumers. It is planned that a new regulation will be introduced in 2026. A suggestion was made by the Federal Network Agency, which is discussed with relevant stakeholders (8undesnetzagentur 2024).

With regard to electrification, stakeholders valued the §19(2) regulation as a necessity for competitive electricity prices. Without this reduction, investments in electricity-based technologies seem even more unlikely. Stakeholders also stated that without these exemptions, some companies would face existential difficulties [2]. One stakeholder emphasised that a reform of the grid charges would still need to contain some form of cost relief for industrial companies so that they can compete internationally [7]. Stakeholders therefore stated that if these cost reliefs would end, this could be interpreted as an obstacle [5, 7]. From this it follows that all factors threatening the cost reduction that is currently granted would make investments in electricity-based technologies unlikely.

Also, if an investment in an electricity-based technology would change the load profile in a way that would threaten receiving grid fee exemptions, this investment is highly unlikely. This also comprises a potential increase of the capacity-based grid fee [3]. Therefore, either the regulatory framework would have to change or the ability to flexibly adapt electricity consumption becomes much more important. However, applying flexibility to meet relief conditions, which stem from a system with only a low share of renewable energies, does not seem to make sense. Regulation would need to change so that flexibility potentials would be applied according to the needs of a renewable system and rewarded with cost reliefs accordingly.

Based on the high potential costs that industrial consumers may face due to a change of their consumption profile, this barrier to the electrification of industrial companies can be assessed as important.

**EU ETS – price level, volatility and free allocation**

The EU Emissions Trading System (European Commission 2023) is one of the key European instruments for achieving emission targets. Companies in the energy sector, energy-intensive industry, aviation and, in future, international maritime transport require a tradable certificate for emitting one tonne of $CO_2$. The quantity of available emission allowances decreases every year. A continuous price increase is therefore intended to provide an increasing incentive to avoid emissions. An evaluation at the end of the third regulatory period (2013-2020) of the trading system came to a positive conclusion: the target reduction of 21% was significantly exceeded; 41% of emission reductions were achieved (Erbach and Foukalová 2022). However, this achievement was attributed less to the price signals of the EU ETS and more to other measures, such as the expansion of renewable energies (Marcu et al. 2021).

Upon closer examination, it becomes evident that only a small portion of the overall reduction occurred in the industrial sector. The barely changed emissions intensity of the industry indicates that much of the emissions reduction was due to decreased economic activity (a decline in production), e.g. resulting from the COVID-19 pandemic.

Lilliestam et al. (2021) conducted a literature review and reached a similar conclusion. None of the articles they analysed found that the EU ETS had a significant impact on the adoption of low-emission technologies in industry during the first or second trading periods. This can be assumed for the third regulatory period as well, as no emission reduction could be observed. This conclusion was also drawn by Mandaroux et al. (2023). They analysed 43 academic papers examining the EU ETS's influence on innovations and the adoption of low-emission technologies in industry. They found that the EU ETS had failed to trigger a technological transformation to date; no technological breakthrough had occurred. Even the adoption of low-emission technologies was limited. The literature cites various past adjustments to the EU ETS design as a reason for its insufficient impact. However, it also highlights that the EU ETS could become more effective with further adjustments.

Stakeholder feedback also confirmed that the correct design of this instrument is highly relevant. Ten out of 13 stakeholders [1, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13] commented on the EU ETS. Some stakeholders rated its steering effect as good [3, 4, 6, 7, 9]. Others assessed the steering effect as not yet relevant [8, 12]. The reason for this is that the allowance price was deemed too low in 2022 [8, 10].

Overall, stakeholders described the EU ETS as fit for purpose. Currently, incentives are rather low and do not suffice to motivate a technological change. However, it is expected that this will change in the near future due to the reduction of allowances and the increase in prices. Therefore, this mechanism cannot be described as a major barrier, but rather as a barrier that is of little relevance.

*Price level and price volatility of emission allowances*

Stakeholders mentioned uncertainty with regard to the price development as an obstacle [6, 11] as well as high price volatility [6, 11, 12]. Although it was clear that the number of allowances would be reduced over time, there was still uncertainty about their future price development [11, 12]. One reason for this is a lack of commitment from decision-makers at the European level. The current price development also was considered as very volatile [6, 11]. Stakeholders named a minimum and maximum price as a possible instrument to reduce this volatility [9]. However, the difficulty of reaching an agreement on the level of minimum and maximum prices at the European level was mentioned as a challenge [11].

Stakeholders discussed the volatility of allowance prices and price volatility in itself as sources of uncertainty. Mechanisms like a price cap were suggested to limit the variation of prices. Nonetheless, the price path that can be expected is rather clear. Therefore, the price level and its volatility cannot be interpreted as a barrier of high relevance.

*Free allocation of emission allowances*

Among the stakeholders, there were different assessments of the free allocation of emissions allowances, by which free emission allowances are given to companies in international competition as defined by the European Union (European Commission n.d.). This allocation was the main instrument to protect sectors in fierce international competition. As companies outside the EU are not exposed to the EU ETS, manufacturing is realised with lower costs. In order to prevent companies from these sectors leaving the EU, free allocation was implemented.
As of 2023, based on Regulation 2023/956 of the European Union, free allocation has been substituted by the Carbon Boarder Adjustment Mechanism (CBAM). CBAM will introduce the necessity for foreign companies to acquire emission allowances at a gradually increasing share of the overall emissions from 2026 to 2034. This is complemented by the reduction of free allocation of emission allowances at the same level, thereby substituting this mechanism from 2034 onwards.

At the time of the interviews, the interviewees had different views on free allocation. On the one hand, it was seen as not helpful, while others viewed it as not problematic. Proponents expressed that free allocation would also lead to emission reductions and the application of low-emission technologies [3, 5, 11]. They argued that the entire quantity of the cap was relevant [3]; it was thought that it would inevitably lead to a reduction in emissions due to a rising price with decreasing availability of allowances. Another stakeholder [5] justified the need for free allocation by arguing that old processes must continue to be economically viable. Without free allocation, the need to purchase emission allowances could deplete financial resources needed for investments in low-carbon technologies. It was argued that free allocation could also serve as a financing instrument. Companies could sell free emission allowances and thereby finance investments. According to another stakeholder, free allocation still incentivises a change in technology because companies consider the opportunity costs of not selling free allowances [11]. They would therefore be faced with the decision of reducing emissions and selling the emission allowances or continuing to operate fossil-based processes.

Various stakeholders argued against free allocation [4, 6, 12, 8]. One stakeholder [4] stated that free allocation would lead to companies mitigating fewer emissions than possible. Another [6] compared the abolition of free allocation with the abolition of an obstacle to technological change. According to a third stakeholder [8], the EU ETS would be more effective with higher prices and the abolition of free allocation. According to one stakeholder [12], free allocation in its original form was a flaw of the EU ETS. This has now been remedied by the abolition of free allocation for 2026 to 2034 (International Carbon Action Partnership 2023).

For some stakeholders, the benchmarking of greenhouse gas emissions as a means of determining the amount of free allowances a company receives has a positive impact on the effectiveness of the EU ETS. One stakeholder [7] pointed out that benchmarking creates incentives, particularly by including new installations in the comparison. One stakeholder [6] criticised the fact that this removes protection in international competition. However, this benchmark could also be improved, according to one stakeholder [10], by including electricity-based processes. This would provide a further incentive for investment.

As the free allocation of emission allowances has been addressed in regulatory changes, it can no longer be interpreted as a barrier. Also, stakeholders had different views on how strong a barrier free allocation was. It was mentioned that the opportunity costs of selling the allowances also act as an incentive to reduce emissions if the prices are sufficiently high.

## 4.2 Energy system factors that hinder the uptake of electricity-based process heat technologies

Apart from economic factors, energy system factors can also pose an obstacle to the electrification of industrial processes. These factors all hinder the use of electricity-based technologies for infrastructural or technological reasons. In the context of the electricity system, these factors include the availability of sufficient renewable electricity and the necessary grid infrastructure to transport it. Also, the technological readiness of electrification technologies defines how well they can compete with conventional, gas-based technologies. Beyond this, the limited capacities of permitting authorities can pose a barrier to electrification.

**Availability of renewable energies**

With regard to the sufficient availability of renewable electricity, different studies on the decarbonisation of the German industrial sector identify electrification as a key component which will lead to an increase in electricity demand. Fleiter et al. (2024) explore electricity-based and hydrogen-based scenarios of industrial decarbonisation. They conclude that up to 2050 the industrial electricity demand increases independently of the scenario. This is mainly driven by the additional electricity demand caused by an electrification of process heat. In 2045 this additional demand ranges from 66 TWh in hydrogen-based scenarios to 201 TWh in electricity-based scenarios. They assume a high availability of renewable electricity, infrastructure and technology readiness.

IN4climate.NRW (2022) sees the possibility of insufficient green electricity as a threat to the electrification of industrial processes. In their 'Climate Paths 2.0' study, the BCG (2021) identified the expansion of wind and solar as one of the main goals of decarbonising the industry. According to the study, 480 GW of wind and solar, which comprise the complete tapping of potentials, will be needed to meet the complete industrial electricity demand of 990 TWh. Similarly, Agora Industrie (2018) identified the sufficient availability of green electricity as the central condition that needs to be met for industrial decarbonisation.

During the interviews, different stakeholders emphasised the relevance of the availability of renewable electricity. Seven of 13 interviewed stakeholders expressed that the expansion of renewable energies is highly relevant [1, 4, 5, 8, 10, 12, 13]. Two stakeholders [1,4] stated that the availability of green electricity is currently insufficient, which raises the question of where this energy will come from. Another stakeholder expressed that the expansion of renewable energies should be the highest political priority [10]. It was also stated that the current expansion plans in the German federal states are not sufficient for reaching the goals of the energy transition [12]. Therefore, the insufficient availability of renewable energies can be assessed as a highly relevant barrier.

The absence of sufficient renewable energies can be interpreted as a severe barrier to decarbonisation by means of electrification. Stakeholders mentioned that it is not clear whether a sufficiently high speed can be reached with regard to the expansion of renewable energies so that industrial energy demand will be met.

**Limited technology readiness**

Although technological readiness has already been reached for technologies in the low to medium temperature range, especially in higher temperature ranges, technological development is currently not sufficient. Fraunhofer ISI (2024) review the possibilities of industrial electrification and state that 60% of industrial heat demand could already be electrified by technologies today. Other technologies need further development for this ratio to increase to 90% by 2035.

Stakeholders expressed that electricity-based high temperature technologies are not yet ready for application [1, 7, 10, 11] and that only limited experience has been gathered with regard to their practical use [11, 12]. One stakeholder [10] stated that it is not possible to electrify processes that need temperatures above 500°C and it is also hardly possible to follow temperature profiles that are needed in certain production processes. For the cement industry, electrification is also not possible as the needed high-temperature plasma burner cannot be operated in a cost-efficient way [7]. Therefore, the cement industry is focusing on hydrogen as an energy carrier, which according to the stakeholder is more energy efficient, compared to the electricity-based process. A stakeholder expressed that, for the brick industry the technological race between the application of hydrogen and electricity has not yet been decided and that further research is currently being conducted to come closer to a decision [8]. Another stakeholder highlighted the necessity of R&D in this area [10]. Three stakeholders highlighted that although different technologies exist, only a small number of projects have been realised [9, 11, 12]; therefore, there is a lack of experience with these types of technologies [3, 12].

It was mentioned that the level of technological readiness was insufficient for high temperature applications that are needed in, for example, the cement industry [1, 7, 10, 11, 12]. In contrast, an application in lower temperature ranges is already possible with technologies that exist today.

### Limited capacity of grid connection

Fraunhofer ISI (2024) stress that generation capacity and the grid connection of industrial sites need to be improved. In this regard, BCG (2021) state that a comprehensive infrastructure programme is needed that aims to expand the electricity grid and to speed up permitting procedures for these infrastructures.

The problem of insufficient grid capacities was also mentioned by different stakeholders [5, 6, 8, 12, 13]. It was mentioned that it was hardly possible to increase the capacity of an already existing grid connection. In some cases, increasing the capacity of grid connection means going up a grid level. The reason is that the needed capacities exceed the capacities that can be provided by lower grid levels. However, without a grid of the corresponding level in proximity of consumers a connection is either very costly or simply not possible [5, 6], as the corresponding grid would need to be expanded in this area [9]. Another stakeholder stressed that grid operators refrain from connection to higher grid levels, and also do not give an outlook on when this could be possible [8]. Stakeholders stressed the necessity of applying early for a connection or an expansion as the assessment and physical connection or increase of capacity on the side of grid operators take a long time [12].

Only one stakeholder [9] expressed that this seems to be of more relevance in the future, as industrial consumers have not yet considered large-scale electrification measures.

Based on the stakeholder feedback, it seems that the current state of grid development is in many cases not sufficient to allow capacity to be increased and electricity-based technologies to be installed. However, it can be assumed that not all industrial sites are confronted with this. Therefore, this barrier cannot be assessed as severe, but rather as important.

### Long permitting procedures of industrial projects, renewable power plants and CCUS

Seven stakeholders discussed the duration of permitting procedures as possible barriers to the decarbonisation of industry [1, 7, 9, 8, 10, 12, 13]. A stakeholder stated that although permitting procedures are generally long, they do not constitute a high barrier, but rather a delay [1]. They could not identify this as a major barrier to industrial electrification. Another stakeholder [10] described the long permitting procedures not as a general problem, but rather as the *‘straw that breaks the camel`s* *back.*' However, they added that viewed from a long-term perspective, permitting durations of up to a year should not pose a high barrier to electrification projects. Another stakeholder [12] had the same impression. Although permitting procedures can take a long time, they are reliable. Other stakeholders [9, 13] stated that they do not see the permitting duration of electrification technologies as a barrier, but they do see the permitting of industry-owned renewable power plants as such. Similarly, a stakeholder [8] stressed the long duration of permitting procedures of renewable energies, but also projects internal to industry, such as warehouse extensions for smaller companies as a general problem for the decarbonisation of the brick industry. Moreover [13], the slow permitting of renewable power plants in general was deemed problematic as many companies aim to sign a PPA contract, for which the power plants need to be built. Another stakeholder stressed [7] that not the permitting duration of electrification is a barrier, but rather the permitting in the field of CCUS.

All in all, stakeholders assessed this barrier as having a low relevance. Although stakeholders reported challenges with lengthy permitting procedures, they did not perceive it to be a major challenge.

## 4.3 Capabilities of businesses to invest in electricity-based process heat technologies

In this chapter, findings are presented regarding barriers to the capabilities of businesses to invest in electricity-based heat technologies. This capability can be influenced by the cost structures of electricity-based technologies, but also how investment decisions are made in companies.

Investment costs and amortisation duration of electricity-based technologies differ from already established technologies. They are significantly higher and longer, respectively, which may pose a problem for companies. Especially due to the current investment logic of companies, insufficient funds or the financial focus of reporting to the advisory board, this may pose a barrier to investments.

**High investment costs and long amortisation time**

Electrification measures are characterised by higher investment costs compared to the continuation of fossil-based industrial processes (Agora Industrie 2022; Geres et al. 2021). This was not only described by German researchers, but also by researchers in the US (Deason et al. 2018; Wei et al. 2019). Higher investment costs alone would not necessarily be a barrier; however, in combination with long amortisation times, these electricity-based technologies become less attractive compared to their fossil counterparts. A recent study conducted by Fraunhofer ISI (2024) adds a layer of detail in this regard. They highlight that especially heat pumps show higher investment costs than alternatives. Also, the combination with thermal storages can increase the investment costs. Different studies recognise this barrier (Fraunhofer ISI 2024; Agora Industrie 2022; 2018; Geres et al. 2021; IN4climate.NRW 2021).

The topic of high investment costs was also discussed by interviewed stakeholders [8] and that the logic of investment decisions needs to change [10, 12]. Longer amortisation periods and higher investment costs need to be incorporated into decision-making in businesses. Investment decisions and planning should be made on a long-term basis with a time horizon of 20 years. A 5-year planning horizon is still the rule today. Family-run companies would be an exception here, according to two stakeholders [10, 13]. These would orientate investments more towards possible future developments.

Stakeholder stated that the investment in electricity-based technologies follows a new investment logic. Investment conditions and amortisation times differ from established technologies. However, it does not seem that this is a major ‘show stopper’ for electrification; rather, it can be assessed as important.

### Focus on maximising financial benefits in companies with external management

Stakeholders [9, 10] specified as a problem that operational reporting focused on financial parameters. This is particularly evident in externally managed companies, i.e. those in which a management team is employed by the company owner to lead the business. Their employment is usually limited to five years. The supervisory board is the controlling body. They often have shares in the company, which makes them direct beneficiaries of a positive annual financial statement and influences the company's decisions. This is generally an influence that shareholders have on company decisions [9]. In the context of this reporting, investments in technologies with long amortisation periods, such as heat pumps or renewable power plants, are simply unattractive [10]. With such investments, it is difficult to realise a profit in, for example, 5 years.

A stakeholder [8] additionally described that electrification measures are of low relevance for companies, which poses an obstacle to a technical transformation. They made the experience that in good economic times, companies tend to skim off profits rather than make investments. Paradoxically, in times of crisis, there is a lack of capital to make investments, as described above.

It does not seem that this barrier is highly relevant as only a small number of stakeholders mentioned it during the interviews. To the majority of stakeholders, it does not seem important and therefore this barrier can be assessed as having little relevance.

### Availability of external capital for investments

Another stakeholder [9] noted that internal funds are not being utilised to a large extent for electrification investments, as this capital is often used for other purposes [8]. This makes external capital particularly relevant. The same stakeholder stated that high costs of natural gas that were experienced in the energy crisis in 2022, which should be a driver of investments in electrification, pose a threat to investments as high fuel costs reduce available funds. This stresses the relevance of external capital.

According to another stakeholder [9], the problem lies more in accounting requirements [9]. Loans are often only granted when little debt is recognised on the balance sheet. It is therefore difficult to borrow capital for decarbonisation projects if other investments have already been made. Another stakeholder [10] considered this hurdle to be less serious. There are a large number of financing options that would enable a technical switchover. One example is the KfW loan programme (KfW 2022).

Only a small number of stakeholders discussed this barrier and their assessments also differ. From this, it can be concluded that this barrier has little relevance.

## 5 Summary of research results

A variety of barriers to the electrification of the industry was identified through a literature research and stakeholder interviews. Results show that barriers exist especially in the area of operating costs of electricity-based technologies and systemic factors. Factors in the field of investment decisions were not deemed to be relevant by stakeholders, which supports the literature findings.

**Operating costs of electricity-based process heat technologies**

The operational costs of technologies were deemed to be the most important factor when it comes to the electrification of industrial processes. Factors like high electricity prices that are influenced by the electricity market design, price components like taxes or grid fees put electricity-based technologies in a worse state compared to conventional gas-based technologies. It was concluded that as long as an electrification leads to higher costs, no company would engage in such an investment.

Stakeholder stated that in the current market design, the cost advantage of renewables is not visible for consumers due to uniform pricing. Also, this leads to the coupling of the gas and the electricity price when gas power plants set the market price. Due to efficiency losses the electricity price for a single kWh will be higher than the gas price, making it hard to reach a price spread between the two energy carriers that favours the investment in electricity-based solutions.

Electricity price components were deemed mostly relevant for companies that do not benefit from cost exemptions. Especially the regulation on reduced grid fees is highly relevant for German industry. Industries are not likely to invest in electricity-based technologies if it could lead to load profiles that would threaten cost relief or may lead to higher capacity prices.

**Energy system factors that hinder the uptake of electricity-based process heat technologies**

On the level of systemic factors, the availability of renewable energies was mentioned in particular as the most important aspect. Without cheap and abundant renewable electricity, it will hardly be possible to decarbonise industry. This includes sufficient grid capacity and grid access for industrial sites, which is currently not necessarily given.

Also, the technological level of electricity-based technologies for higher temperatures was deemed to be too low for practical application. Technologies in the low temperature range show a sufficient technological level. Different stakeholders pointed out that further research and development would be necessary to make specialised technologies applicable in practice.

A barrier assessed as hardly relevant was lengthy permitting procedures. Stakeholders rarely assessed this as a broad problem; it was rather of relevance for single companies.

**Capabilities of businesses to invest in electricity-based process heat technologies**

Few barriers were identified in this category. In particular, the investment logic seems to be problematic at present. Stakeholders stated that this is still based on the techno-economic characteristics of conventional technologies. Also, companies seem to struggle to acquire and use external capital for investments in electricity-based technologies. Another barrier seems to be the financial focus of reporting to the advisory board. Overall, these barriers were not deemed to be highly relevant.

# 6 Conclusions

Transformations are complex undertakings in which different stakeholders take part. Starting and steering a transformative process in a sustainable direction is connected with large efforts. Due to the immense efforts and resources required to manage such a transition, the state has an important role to play. This is the conclusion of chapter 2.1.

The overall system transformation towards climate neutrality consists of a range of transformations in different sectors, which are also influenced by many different factors. As presented in chapter 2.2, the decarbonisation of industry is particularly relevant. In contrast to other sectors, such as the electricity sector, emissions have hardly declined and new climate-neutral technologies are barely applied in practice. With an ongoing reduction of emissions in other sectors, the share of stable industrial emissions will increase, as will the importance to reduce emissions to meet climate goals. Effective policies are needed to get the sustainable transformation of this sector on track.

However, policymakers need a clear understanding of which policies can speed up the industrial transformation. To design effective measures, they require insights into the barriers that hinder the adoption of decarbonisation technologies. This paper addresses the knowledge gap by examining these barriers. Our research focuses on electrification as a key strategy for reducing industrial emissions. To explore this, we conducted a literature review and interviews in 2022 (see chapter 3).

Empirical results from interviews and the literature on industrial decarbonisation support the findings on transformation in chapter 2.2: industrial transformation through electrification is a complex multi-level problem. Companies face barriers on many different levels. This underlines the important role that the state has to play in coordinating a policy mix that solves these problems. Results from our research points out what needs to be addressed to make electrification possible.

Chapter 4 provides an overview of the barriers identified in the research for this paper. They were divided into the following categories:

- operating costs of electricity-based process heat technologies,
- energy system factors that hinder the uptake of electricity-based process heat technologies, and
- capabilities of businesses to invest in electricity-based process heat technologies.

Stakeholders highlighted that the operating costs of electrification technologies are the main hurdle to applying electrification technologies, see chapter 3.1. Electricity prices and its components have a significant impact on the decision to invest in electrification technologies. Especially in 2022, which saw very high energy prices, stakeholders pointed out the importance of driving electricity prices down. The level of these prices depends on both the market price and price components such as grid fees or taxes.

To drive down electricity prices, different policies are needed, which address the different problems on their respective levels. Especially measures that lower the electricity prices and make electricity-based technologies economically feasible in the face of prevailing gas prices are very important. Stakeholders also stressed the importance of planning security with regard to electricity prices, which is needed to engage in a technological change towards electrification. In 2024, different measures specified as important by the stakeholders were implemented: the electricity tax was reduced to the European minimum and carbon contracts for difference were introduced. Some stakeholders questioned whether the current market design is able to reflect the low generation costs of renewable electricity. However, they were not able to point out how the design should evolve.

Stakeholders also pointed out different barriers on a systemic level, see chapter 4.2. In particular, the availability of sufficient renewable electricity and grid capacity were deemed to be highly relevant. On the level of single industrial sites, electrification goes hand in hand with increased grid capacity needs, which means that the expansion of the site's grid connection is necessary if electrification shall be realised. Depending on where the site is situated, this is not necessarily possible as the next grid connection point of a higher level is too far away or higher grid only has an insufficient capacity.

Stakeholders pointed out that for higher temperature levels, there are currently no technologies that fulfil the needs of industrial companies. Research and development is therefore deemed very important to increase the energy efficiency of these technologies and their ability to flexibly alter the temperature.

This shows the high importance that stakeholders assigned to the infrastructure and technologies that are needed to electrify industry. Renewable electricity and its transportation on the supply side as well as electrification technologies that can meet industrial needs on the demand side are the basis for electrification. From a policymaker point of view, this points out how important it is to continue renewable expansion and the expansion of the transmission and distribution grid alike and support further technological development of high temperature electrification technologies.

When deciding on an investment, not only operating costs, but also investment costs are considered. However, in this field less relevant barriers were named by stakeholders, see chapter 4.3. Higher investment costs and long amortisation times were described as problematic. Conventional technologies show lower investment costs and shorter amortisation times, which is especially important in the light of financial reporting towards the advisory board. This problem needs to be addressed as the logic of investments and return on these investment needs to change. Policies that support investment can help to overcome this barrier. However, in the long term, investments should be realised without governmental support.

It can be concluded that industrial transformation through electrification exacts high demands on policymaking. Industrial electrification is hindered by a combination of different barriers: high electricity prices, insufficient infrastructure and unattractive investment conditions, among others. Policymakers therefore need to design a policy package that addresses these different problems in order to support industrial electrification and enable the transformation of this sector towards net-zero carbon emissions.

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