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Exploring Barriers to Heat Pump Adoption in Industry: Insights from a Survey

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The data underlying this study cannot be made openly available due to participant confidentiality. Further information is available from the corresponding author upon reasonable request.

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The authors confirm that all the research meets ethical guidelines and adheres to the legal requirements of the study country. Formal approval could not be obtained, because there was no ethics or institutional committee in place at the authors' institutions at the time the study was conducted. Informed consent was obtained from all participants.

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No AI tools were used to generate original research content, create or manipulate research data, conduct the analysis, or produce substantive intellectual contributions. All research design, data collection, analysis, interpretation of findings, and scientific conclusions were performed exclusively by the human authors. The authors reviewed and verified all AI-assisted outputs and take full responsibility for the content of this manuscript.

Exploring Barriers to Heat Pump Adoption in Industry: Insights from a Survey

Abstract

Electrifying industry is a key driver to achieve European climate targets while remaining competitive. For process heat, market-ready technologies like large-scale heat pumps offer significant potential to cut greenhouse gas emissions and boost energy efficiency. Beyond energy-policy driven aspects like the ratio of electricity to gas prices, time-variable electricity tariffs, and investment subsidies, knowledge-based factors are probably also have considerable influence on market penetration.

This study is part of a broader action research initiative that combines diffusion analysis with the co-development of instruments supporting information cascades and reducing adoption barriers. To ensure that instruments developed meet industry needs, we conducted a survey on market diffusion of large-scale heat pumps. The questionnaire was developed in two steps: first, expert interviews were conducted at a professional trade fair for air conditioning and refrigeration technology to identify drivers and barriers. Based on this, a questionnaire was developed inspired by a typical business-to-business purchasing process, while focusing on identifying relevant actors, drivers and barriers.

The online survey addressed approximately 615 industry professionals and was conducted between March and June 2025. We received 48 responses, with 31 referring specifically to process heat. Our findings show that integration into existing production structures and the need for technical expertise are seen as particularly challenging and important aspects for further market penetration. These findings suggest that support instruments should focus primarily on these aspects.

Keywords: large-scale heat pumps, process heat, market penetration, barriers, industry, Technological Innovation Systems

1. Introduction

According to the German Climate Protection Act, Germany must achieve climate neutrality by 2045. This requires fundamental changes in energy use, particularly regarding process heat in industry, which remains heavily dependent on fossil energy sources. As process heat installations represent long-living capital goods, it is essential to establish clear directional signals as early as possible.

From an energy system perspective, the electrification of process heat offers particularly promising potential for enhancing macroeconomic energy efficiency, as demonstrated by various modelling studies (Ariadne 2024; Fleiter et al. 2018). This can be achieved, for example, through direct electric solutions or large-scale heat pumps, which have the potential to generate substantial efficiency gains in specific applications.

While considerable attention has been devoted to technological research and development in recent years, a rapid market diffusion of innovative process heat technologies can be particularly facilitated when end-user companies actively engage with these technologies and make informed decisions. To effectively support the transition phase from research to market penetration, it is necessary to understand the processes, mechanisms, and actors involved, thereby enabling the development of supporting instruments to reduce barriers and raise awareness.

1.1 Research context and approach

This study is embedded in an interdisciplinary action research initiative – Wärmeeffizienz durch Industrielle Transformation (WEIT; Heat Efficiency through Industrial Transformation) – which aims to develop instruments that accelerate market penetration of energy- and climate-efficient process heat solutions in industry. The initiative comprises three interconnected work streams.

First, a diffusion analysis was conducted to identify drivers and barriers to market penetration for a defined technology scope, incorporating technical, economic, and knowledge-related dimensions.

Second, feasibility studies are being prepared for two energy-intensive companies producing chlorine, generating practice-relevant knowledge on specific efficient process heat solutions.

Third, building on the diffusion analysis, potential instruments such as technology blueprints, decision-making guidelines, and technology scouts are being developed within a co-creation approach. Workshops with practitioners identify beneficial structures, followed by piloting and testing of the developed instruments.

The present paper focuses on the first work stream – the diffusion analysis – which provides the empirical foundation for instrument development in the co-creation process.

1.2 Technology scope: Large-scale heat pumps

The technology scope for this study was informed by insights from parallel feasibility studies conducted within the broader research initiative (cf. second work stream of previous section).

One of the two companies being assessed already operates a large-scale heat pump and is planning to expand it; the second is evaluating the integration of a large-scale heat pump (i.e., a heat pump with an output exceeding 100 kW_{th} according to VDI Guideline 4646). Interim findings from these studies revealed substantial potential for large-scale heat pump integration in industrial settings, particularly when combined with cooling applications.

This led to the decision to focus the diffusion analysis specifically on large-scale heat pumps for the following reasons:

- Large-scale heat pumps constitute a technically mature, market-ready solution that has moved beyond research and development.
- Despite technical maturity, large-scale heat pumps currently remain in a niche market position, making the transition from niche to mainstream adoption the central challenge.
- While innovative research and development activities continue to expand the potential of large-scale heat pumps – for example through higher supply temperatures and environmentally friendly refrigerants – one central challenge at this stage lies in facilitating upscaling and broader market diffusion.

1.3 Literature on market diffusion of large-scale heat pumps

In recent years, residential heat pumps have experienced rapid growth and are widely expected to become the default heating solution for most housing types. In contrast, large-scale heat pump deployment is still lagging behind its potential (Sino-German Energy Partnership 2022). A comprehensive overview of the technology's deployment was provided by David et al. (2017), who identified 1.5 GW_{th} of installed total heating capacity across Europe in 2017. Since then, deployment has continued to increase. A 2021 survey by Euroheat & Power reported 2.5 GW_{th} of installed capacity within European district heating and cooling systems. Nevertheless, this corresponds to only around 1% of total installed district heating and cooling capacity in Europe. At the same time, district heating is projected to reach a market share of up to 50% of heat supply in Europe by 2050, with an estimated 25–30% of installed capacity potentially based on large-scale heat pumps (David et al. 2017; Euroheat & Power 2022). This projection highlights the substantial untapped potential of the technology and underscores the niche position it currently remains in (Agora Energiewende 2023; Volkova et al. 2022). A similar pattern emerges in industrial applications. Large-scale heat pumps could play a crucial role in the decarbonisation of low-temperature heat (Marina et al. 2021). In the German industrial sector, accelerating heat pump deployment could reduce gas consumption by up to 25% by 2030 compared to 2021 levels. However, at the beginning of 2023, only 30 large-scale heat pumps (with 500 kW_{th} or more) were in operation in Germany (Agora Energiewende 2023).

The diffusion of new technologies in industrial contexts has been extensively studied across disciplines. Geroski (2000) provides a foundational overview, noting that while much of the literature focuses on mathematical models explaining the characteristic patterns of technology adoption, the underlying qualitative mechanisms are of particular relevance for understanding – and influencing – diffusion processes. Geroski's analysis emphasises the importance of broader market dynamics, firm-specific characteristics, and inter-organisational processes – particularly the role of knowledge transfer. Likewise, empirical studies on the large-scale heat pumps in Europe also suggest that these factors are also central to their diffusion, acting as both drivers and barriers.

Existing literature identifies several technical barriers to the widespread deployment of large-scale heat pumps, including limitations related to heat sink temperatures and the availability of suitable

refrigerants. However, these constraints are expected to diminish progressively as technological development advances (Arpagaus et al. 2018; Jesper et al. 2021; Wolf 2017). As a result, non-technological barriers including economic and policy-related factors are becoming increasingly relevant. These barriers particularly relate to the high ratio of electricity prices compared to gas and oil prices in many countries, which undermines the economic competitiveness of heat pumps in many European countries, particularly in Germany. This imbalance is partly driven by electricity levies and taxes, which are more pronounced in Germany (Agora Energiewende 2023; Wolf 2017). These market dynamics can thus be strongly influenced by policy frameworks, e.g. the level of carbon pricing applied (Agora Energiewende 2023). Together with the high upfront capital costs and long payback periods, non-standardised or frequently changing support schemes can create regulatory uncertainty, which further discourages firms from transitioning to heat pump solutions (Adamo et al. 2025; Dosumu et al. 2024).

Firm-specific characteristics and dynamics also play a critical role. Integrating large-scale heat pumps into existing industrial processes often requires customised system design and significant process adaptation, resulting in additional costs and organisational complexity (Arpagaus et al. 2018; Jesper et al. 2021). Geroski (2000) further emphasises that diffusion is shaped by absorptive capacity, switching costs, and the ability to integrate new technologies into existing production structures.

Beyond individual firms, diffusion processes are shaped by inter-organisational dynamics. Firms operate within broader networks characterised by competitive pressures, evaluations of a technology's legitimacy, and knowledge exchange (Geroski 2000). Knowledge gaps regarding large-scale heat pumps – exacerbated by a lack of standards, guidelines, pilot and demonstration projects, and training opportunities – have been identified as barriers for the technology's diffusion (Arpagaus et al. 2018; Jesper et al. 2021). In this regard, Geroski (2000) suggests to differentiate between 'hardware' and 'software' aspects of new technologies: while information about the existence of a new technology (hardware) can spread relatively quickly, the tacit knowledge required to use it effectively (software) must often be transmitted through direct, word-of-mouth contact between users. This has profound implications for diffusion speed and pattern. Importantly, when early adopters share their experiences and the technology gains acceptance, information cascades and network effects can accelerate adoption among subsequent users. Conversely, knowledge deficits, perceived risks, and integration challenges can constitute significant barriers that slow or even prevent diffusion.

1.4 Our contribution

This paper contributes to the literature on industrial heat pump adoption in several ways. First, while existing research has predominantly focused on technical and economic barriers, we adopt a socio-technical perspective that explicitly incorporates organisational and knowledge-related factors influencing adoption decisions. Second, our diffusion analysis combines qualitative expert interviews with a quantitative survey, we employ a mixed-methods approach that enables both in-depth understanding of barrier mechanisms and broader validation across a sample of industry practitioners. Third, our analysis is explicitly practice-oriented: rather than merely identifying barriers, we contextualize our findings to inform the subsequent development of instruments within the broader action research initiative (cf. third stream of work described in Section 1.1). Finally, by focusing on innovators and early adopters – companies that have already engaged with or are actively considering large-scale heat pumps – we provide insights into the specific challenges encountered at the current stage of market development, where the transition from niche to mainstream adoption is the central concern.

2. Methods

The diffusion analysis is structured in two sequential parts. First, hypothesis formulation regarding drivers and barriers to market penetration was conducted. Building on this, a quantitative survey was carried out to validate the hypotheses and establish priorities for subsequent instrument development within the broader action research initiative.

2.1 Hypothesis formulation

The hypothesis formulation was implemented using the Technological Innovation Systems (TIS) framework. This heuristic analytical framework is well-suited for diffusion analysis as it systematically

captures the functions that can support or hinder market penetration processes (see step three in Figure 1).

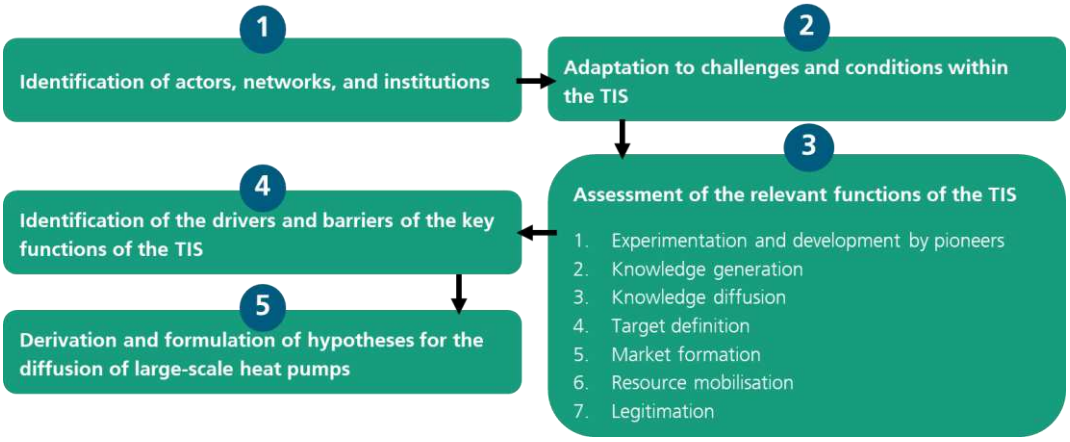


Figure 1: Flowchart showing hypothesis formulation process within the diffusion analysis. Own illustration aligned with Bergek (2019) and Wieczorek et al. (2013)

The hypothesis formulation was empirically grounded through a series of qualitative expert interviews. Interview findings were synthesised and combined with insights from the literature to inform hypothesis development. The interview data were analysed qualitatively within the TIS framework, focusing on identifying drivers and barriers relevant to the framework's functional categories. Details on interview timing, the venue, and interview participants are provided in Section 3.1.

2.2 Survey design

For the quantitative survey, a questionnaire was developed that combined insights from the qualitative expert interviews and hypothesis formulation (Section 2.1) with domain-specific expertise. The questionnaire development followed a four-step process:

1. **Mapping the purchasing process:** The business-to-business (B2B) purchasing process according to Kleinaltenkamp and Saab (2021) was mapped in ten phases to provide a structured foundation for the questionnaire. These phases comprise: problem recognition, definition of performance requirements, specification of performance characteristics, supplier search, evaluation of supplier attributes, solicitation of offers, assessment of offers, supplier selection, order processing, and control and evaluation.
2. **Assigning drivers and barriers:** The drivers and barriers identified through the qualitative expert interviews were assigned to the respective purchasing phases.
3. **Assigning actors to purchasing phases:** Relevant actors were identified and assigned to each purchasing phase.
4. **Developing differentiated questions:** In a final step, the preceding steps were combined as preparation for a brainstorming session to create thematic clusters and formulate differentiated questions for the online survey, with a focus on identifying relevant topics for technology diffusions which may be addressed by subsequent instrument development.

3. Data

3.1 Qualitative expert interviews

The qualitative expert interviews were conducted predominantly at the Chillventa trade fair in Nuremberg, Germany, in October 2024. This venue, a leading exhibition for air conditioning and refrigeration technology, was deliberately chosen as the combined generation of heat and cooling tends to increase the efficiency and economic viability of large-scale heat pumps. Findings from the parallel feasibility studies conducted as part of the action research initiative for chlorine producers have supported this thesis.

Preparatory activities included researching exhibitors at Chillventa, compiling existing contacts, and scheduling appointments via email and telephone. A semi-structured interview guideline was developed prior to data collection.

Finally, semi-structured, guideline-based interviews were conducted with representatives from large-scale heat pump manufacturers, academia, the heat pump association, education and training institutions, and policy consultancy. Interviews took place predominantly in person at the trade fair, with additional interviews conducted via telephone or online. Each interview was conducted in teams of two: one researcher led the interview while the second took structured field notes. Interview data were analysed qualitatively within the TIS framework.

Key data on qualitative expert interviews

- Timing: October 2024
- Location: predominantly Chillventa trade fair, Nuremberg, Germany
- Total number of interviews: nine
  - four with large-scale heat pump manufacturers
  - four with representatives from academia and associations,
  - one with policy consultancy representatives
- Interview mode: seven in person, two remote (telephone/online)
- Interview duration: approximately 30–60 minutes

3.2 Quantitative survey

The online survey was distributed through various channels, including newsletters and social media posts from consortium partners. Additionally, industry stakeholders from the fields of technology and production management were contacted directly, drawing on contacts established in previous projects. To increase the response rate, contact details of Eco-Management and Audit Scheme (EMAS) managers for industrial companies were also researched, as energy and environmental managers were part of the target group.

Due to the current niche character of large-scale heat pumps in industry, we assume that our sample is not representative but rather reflects the perspective of innovative companies. Nevertheless, we consider that many findings are also transferable to other early adopters. Figure 2 provides an overview of our sample.

Key data on quantitative survey

- Field phase: March to mid-June 2025
- Target group: energy management professionals from industry
- Distribution channels:
  - newsletters and social media posts
  - direct contact with 75 industry stakeholders
  - approximately 540 EMAS managers researched and contacted
- Total contacts: approximately 615 potential participants
- Total responses: 48 completed questionnaires
- Response rate: approximately 8%
- Respondents with process heat focus: 31
  - already using large-scale heat pumps: seven
  - planning future deployment: 13
- Questionnaire format: predominantly Likert-scale items
- Estimated completion time: approximately ten minutes

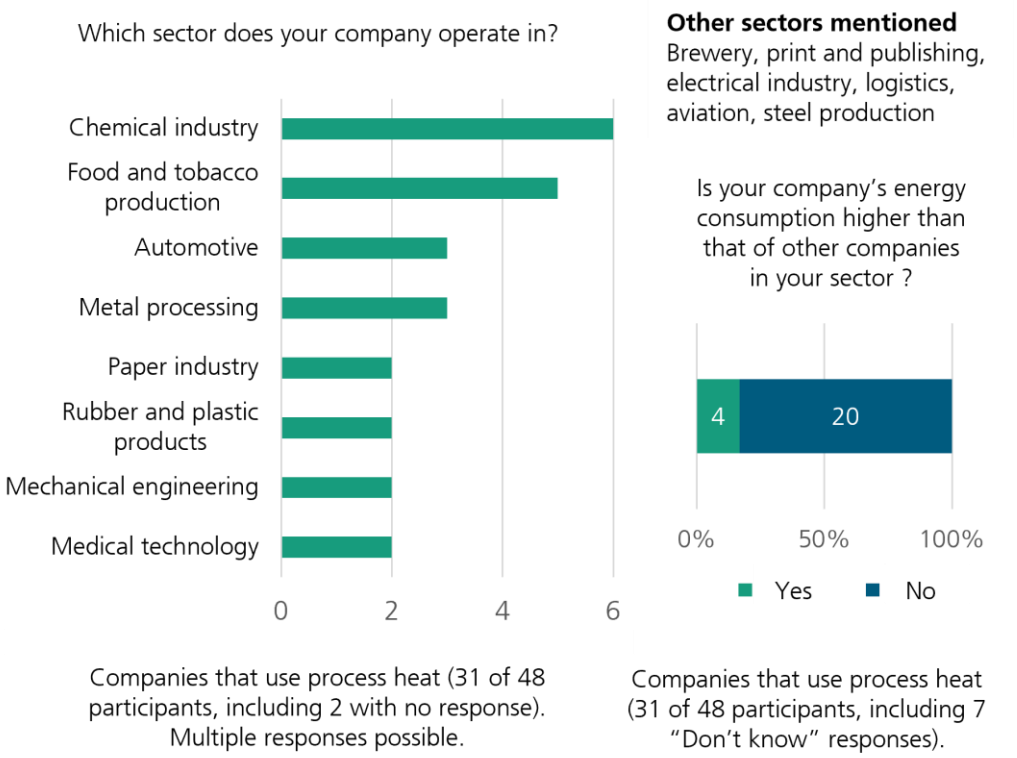


Figure 2: Bar chart showing sample composition

4. Results

4.1 Windows of opportunity for heat pump installation

Figure 3 shows results regarding windows of opportunity for the installation of large-scale heat pumps. As expected, it can be observed that companies plan replacement investments for process heat generation during scheduled maintenance shutdowns.

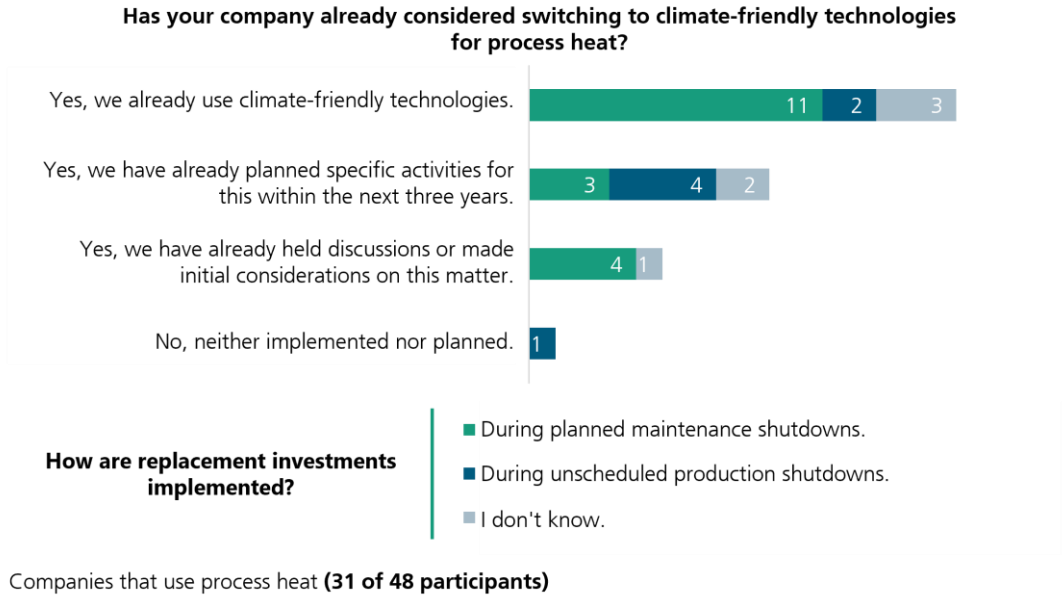


Figure 3: Chart displaying timing preferences for heat pump installation

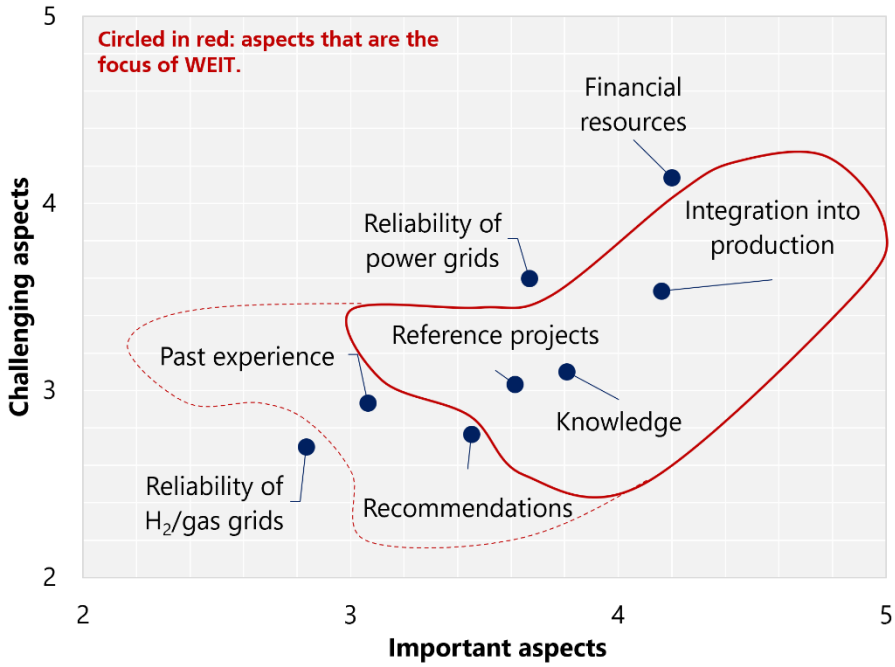
4.2 Important and challenging aspects for market penetration

Figure 4 displays important and challenging aspects for the market penetration of large-scale heat pumps, captured via a two-stage Likert scale. A key objective of this analysis was to identify potential barriers for the technology's diffusion and to establish priorities for subsequent instrument development.

Importantly, this study explicitly focuses on barriers that are not primarily determined by the energy policy framework, as these represent the addressable domain for practical intervention to be addressed by the action research initiative of WEIT. This distinction is visualised in Figure 4 by the red frame, which delineates aspects within the project's scope from those outside it.

Three aspects emerged as particularly important and challenging: 'integration into production structure', 'reliability of electricity networks', and 'mobilisation of financial resources'. Of these, 'financial resources' and 'reliability of energy networks' are predominantly shaped by energy policy conditions – such as the electricity-to-gas price ratio, grid fee structures, and regulatory stability – and therefore fall outside the direct scope of WEIT. Accordingly, the aspect 'integration into production structure' represents the primary focus for subsequent instrument development the action research initiative WEIT. Complementary aspects such as reference projects, technical expertise, and the communication of experiences were also rated as important and can support the adoption process.

The following subsections discuss these three key aspects in detail, contextualised by insights from the qualitative expert interviews and the broader energy policy environment.



The graph shows the weighted average of the responses.
Depending on the aspect, the number of responses varies between 29 and 31.

Figure 4: Matrix plot showing importance versus challenge ratings

Integration into production structure

The aspect 'integration into production structure' stands out, rated by respondents as both highly important and highly challenging. Drawing on insights from the qualitative expert interviews, we contextualise this finding as follows: the perceived challenge likely relates to the risk of production downtime associated with modifications to existing production infrastructure. Correspondingly, the high importance rating reflects the need for solutions that enable seamless integration into established processes. Taken together, these findings suggest that respondents prioritise approaches that minimise disruption to ongoing operations while facilitating the adoption of large-scale heat pumps.

This is further underscored by survey results indicating that the specification of performance characteristics and the identification of suitable suppliers are comparatively challenging. These

findings provide an empirical basis for subsequent instrument development (within the WEIT action research initiative) aimed at addressing precisely these knowledge and integration barriers.

Reliability of energy networks

The aspects 'reliability of H2/gas networks' and 'reliability of electricity networks' should be interpreted in conjunction, as the questions were deliberately posed openly. Notably, respondents rated 'reliability of electricity networks' as both highly important and challenging, whereas 'reliability of H2/gas networks' was considered less important and less challenging. Since we assume that our sample predominantly consists of innovators and early adopters with a positive attitude towards electrification, this pattern warrants closer examination.

Drawing on insights from the qualitative expert interviews and the broader energy policy context, we interpret this finding as follows: companies committed to electrifying their process heat supply – for instance through large-scale heat pumps – have a vested interest in stable and predictable framework conditions for electricity. However, in Germany, the regulatory environment for electricity has undergone considerable changes in recent years, including ongoing revisions to grid fee structures (Netzentgeltsystematik) and adjustments to electricity price components. In contrast, while the natural gas sector also experienced regulatory adjustments – particularly in response to the 2022 energy crisis – these changes were largely reactive and temporary in nature. The electricity sector, by comparison, has undergone more frequent and structurally profound reforms affecting pricing mechanisms, grid fee allocation, and levy structures over the past decade.

Consequently, the high importance rating for 'reliability of electricity networks' likely reflects a demand for regulatory stability and planning security, while the high challenge rating indicates that respondents perceive the current policy environment as insufficiently predictable. Greater (perceived) reliability in terms of transparent and stable electricity pricing structures and grid access conditions would therefore be beneficial for accelerating market penetration of large-scale heat pumps. While this aspect falls outside the direct (practical) scope of the WEIT action research initiative, it represents an important contextual factor for understanding adoption barriers.

Financial resources

Unsurprisingly, 'mobilisation of financial resources' is considered particularly important and challenging. Drawing on insights from the qualitative expert interviews, this also depends on the ratio of electricity prices to the price of the energy carrier currently in use. In the case of process heat, this is typically the ratio of electricity to gas prices. As this aspect is primarily determined by energy market conditions and policy frameworks, it lies outside the direct (practical) scope of the WEIT action research initiative but remains a significant contextual barrier for market penetration.

4.3 Climate protection targets and information acquisition

Finally, the majority of participating companies in the quantitative survey indicated that they have already publicly communicated climate protection targets (see Figure 5). This is probably also a driving force for innovators and early adopters. With regard to information acquisition, approximately one third indicated that they already have specific contacts with actors such as manufacturers, service providers, engineering consultancies, or heat suppliers.

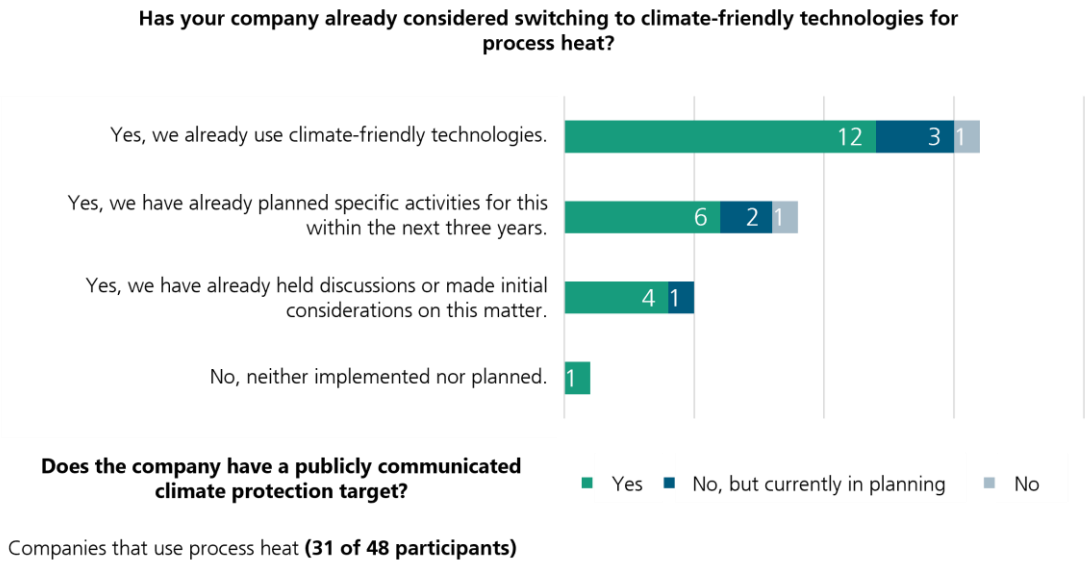


Figure 5: Chart displaying the share of companies that have publicly communicated climate targets.

5. Discussion

Our findings confirm that the energy policy framework constitutes a foundational factor influencing the diffusion of large-scale heat pumps in industry. This is particularly evident in respondents' assessments of the mobilisation of financial resources, which is considered both highly important and challenging. Interviews with experts confirmed that these economic barriers are closely linked to the comparatively high ratio of electricity prices relative to gas and oil prices, which is a structural disadvantage that is particularly pronounced in Germany (Agora Energiewende 2023; Wolf 2017). Beyond economic aspect, the energy policy framework also plays an important role from a regulatory perspective. In this context, the high importance attributed to the reliability of electricity networks likely reflects a broader demand for regulatory stability and planning security. At the same time, the high challenge rating indicates that respondents perceive the current policy environment as insufficiently predictable, which may generate regulatory uncertainty, thereby discouraging firms from transitioning to heat pump solutions (Adamo et al. 2025; Dosumu et al. 2024).

Importantly, our findings also highlight barriers to the adoption of large-scale heat pumps that are not primarily determined by the energy policy framework. One of these relates to firm-specific characteristics and organisational dynamics that might influence the likelihood of technology implementation. In this regard, integration into the production structure stands out, as it is rated by respondents as both highly important and highly challenging. This assessment is likely driven by concerns regarding production downtime associated with modifications to existing production infrastructure and the need for solutions that enable seamless integration into established processes. At the same time, it indicates that the transition to heat pump technology may require significant cultural changes within companies, including adaptations to established routines (Dosumu et al. 2024). Against this background, it is not surprising that the surveyed companies tend to plan replacement investments for process heat generation during scheduled maintenance shutdowns, making these periods particularly important windows of opportunity for interventions aimed at promoting technology adoption.

The risk aversion observed among the surveyed companies, particularly with regard to concerns about integration into production structures, might be linked to the fact that industrial heat pumps constitute relatively unfamiliar technologies. As a result, uncertainties regarding their reliability and the risks associated with transitioning away from well-established heating solutions can represent significant barriers (Dosumu et al. 2024). This unfamiliarity is further reflected in survey results indicating that the specification of performance characteristics and the identification of suitable suppliers are perceived as comparatively challenging tasks. Such knowledge gaps have also been identified as barriers in previous studies (Arpagaus et al. 2018; Jesper et al. 2021). Our findings therefore suggest that inter-organisational exchanges of knowledge and experiences, such as the

dissemination of lessons learned from reference projects, can support the adoption process. In this respect, the results align with previous studies highlighting the importance of coordinated efforts among multiple actors, including industrial firms, policymakers, and researchers. Such collaboration would not only support potential adopters of industrial heat pumps but could also assist policymakers in designing regulatory frameworks aligned with industrial realities and help technology developers design systems better suited to the specific challenges faced by energy-intensive industries (Dosumu et al. 2024).

6. Conclusion

6.1 Summary of findings

This study examined drivers and barriers to the adoption of large-scale heat pumps in German industry, combining qualitative expert interviews with a quantitative survey among (energy) management professionals. Our findings indicate that interest in large-scale heat pumps is considerable. The qualitative expert interviews suggest that rising natural gas and CO_2 certificate prices contribute to this interest. Additionally, our survey results show that companies already using or planning to deploy large-scale heat pumps have typically established public sustainability targets, which we interpret as a further driving force particularly among innovators and early adopters.

However, substantial barriers impede broader market penetration. Three aspects emerged as particularly important and challenging: integration into existing production structures, reliability of energy networks, and mobilisation of financial resources. Of these, the latter two are predominantly shaped by energy policy conditions and thus fall outside the scope of the rather practical oriented action research initiative WEIT. The aspect 'integration into production structure' – encompassing concerns about production downtime, specification of performance characteristics, and identification of suitable suppliers – represents the primary addressable barrier within the (practical) scope of the WEIT action research initiative and thus the recommended focal point for instrument development. Furthermore, these findings support the hypothesis that successful adaptation of large-scale heat pumps cannot be achieved using traditional methods from the 'boiler house', but requires smart integration i.e. such as the integration of excess heat from production – and that market penetration is therefore further characterised by information cascades supported by network effects.

6.2 Implications for practice and policy

Our findings suggest that the current stage of large-scale heat pump diffusion appears to be partly characterised by knowledge deficits that may impede the information cascades and network effects conducive to broader market penetration. Following Geroski (2000), the tacit knowledge required for successful integration of large-scale heat pumps into existing production infrastructure may not be easily codified but likely requires transmission through direct exchange between experienced and prospective users. However, the extent to which such knowledge barriers constrain adoption presumably also depends on market conditions – higher potential returns from technology switching may accelerate efforts to overcome knowledge deficits.

Two key implications emerge from our analysis:

First, the design of support instruments that facilitate knowledge transfer and reduce integration barriers. Given that the complexity of integrating large-scale heat pumps into existing production structures emerged as a central challenge, instruments capable of handling this complexity through interactive engagement appear particularly promising. While established approaches such as technology blueprints, decision-making guidelines, and technology scouts remain valuable, AI-driven tools such as chatbots may offer distinct advantages: unlike static information sources, they can respond to firm-specific queries, accommodate the heterogeneity of production contexts, and incrementally incorporate insights from practitioner exchanges. Human-based approaches like technology scouts share this capacity for interactive problem-solving but are inherently less scalable. A combination of both – AI-driven tools for accessible, on-demand support complemented by human expertise for complex cases – may therefore represent a particularly effective and efficient approach.

Second, the provision of greater regulatory stability regarding electricity pricing structures and grid access conditions would reduce perceived risks for companies committed to electrification (Adamo et

al. 2025; Dosumu et al. 2024). While this falls outside the (practical) scope of the WEIT action research initiative, it represents an important contextual factor that policy actors should address.

Third, it is important to note that large-scale heat pumps are closely linked to the use of industrial excess heat, as previous studies show that the potential for internal heat integration has not yet been fully exploited (Aydemir and Rohde 2018; Aydemir and Fritz 2020) – large-scale heat pumps could be an additional driver for exploiting this potential. Thus, corresponding connections to existing networks and formats in this domain are therefore advisable to maximise synergies and avoid duplication of efforts.

6.3 Limitations

Several limitations should be acknowledged. Our sample likely reflects the perspective of innovators and early adopters rather than the broader population of industrial firms, as participants were recruited through channels associated with environmental management and energy efficiency. While this focus is appropriate for understanding barriers at the current stage of market development – where the transition from niche to mainstream adoption is the central concern – findings may not be directly transferable to later adopter segments. Additionally, the study is limited to the German context; regulatory frameworks and market conditions differ across countries, potentially affecting the generalisability of findings (Adamo et al. 2025).

6.4 Future research

Future research in this domain would benefit from approaches that embrace the dynamic and applied nature of technology diffusion processes. Rather than large-scale econometric studies – which risk becoming outdated before completion in rapidly evolving markets – action research approaches that combine instrument development with concurrent evaluation appear particularly promising. Such accompanying research allows for iterative testing and refinement of support instruments in real-world settings.

Beyond the technology-specific focus of the present study, broader research questions warrant attention. While the advantages of industrial electrification are well established from energy efficiency and energy system perspectives, important questions remain regarding policy design: how can policies be structured such that these systemic benefits are reflected in firm-level incentives and gain broader societal acceptance? This requires understanding the distributional consequences of electrification – identifying winners and losers – and mapping the actor configurations that shape policy implementation. Research addressing these questions at a higher level of aggregation could inform more effective support for industrial decarbonisation across technologies and sectors.

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