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Insights from supply chain workshops and end user case studies

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Summary

Industrial heat pumps offer a tangible decarbonization option to meet the industrial demand for low temperature heat generated without using fossil fuels. Dutch and European governments are championing this technology; specifically, for supplying low temperature process heat (<200°C).

Yet, the current heat pump adoption rate is low. After years of steady growth, overall EU heat pump sales declined in 2023 and 2024, followed by a limited boost in 2025. This growth is concentrated within the residential and utility sectors, with limited adoption in industrial settings. At the current growth rate, current energy security and climate ambitions are unlikely to be met.

Technical and non-technical barriers hamper adoption. Although commercial solutions for low temperature industrial heat pumps are widely available up to 120°C and 10MW, solutions at higher temperatures or larger capacities are either only just entering broader commercial availability (for 120-160°C) or still in the demonstration phase of development (>160°C). Conversely, various non-technical factors (e.g. high investment costs, unattractive gas to electricity price ratios, grid congestion) have been put forward as ecosystem level barriers inhibiting higher levels of adoption. These challenges have been covered extensively and are already addressed in existing EU and Dutch policy frameworks.

However, studies into non-technical barriers lack data from concrete adoption trajectories at end users. While existing studies highlight common barriers at the level of the innovation ecosystem, they lack more detailed insight from specific cases regarding the actual development and implementation process. This research thus focused on the supply chain level and the project level (i.e. a single adoption trajectory at a single end user). The barriers were revealed using a combination of interviews and workshops with actors in the heat pump supply chain and four case studies of heat pump adoption trajectories at companies in the food and paper industries.

At the level of the supply chain, a lack of training in combining heat pump and production process knowledge hampers the integration of heat pumps into existing processes. Supply chain actors perceived a major barrier to be the lack of training in heat pump technology for engineers and industrial technicians, as well as specific training for refrigeration engineers to realign their knowledge with industrial heat pumps (e.g. on natural refrigerants). The lack of combined knowledge of both electric heating technology and production processes is recognised in the literature as a major barrier to industrial electrification.

At the project level, three challenges emerged:

1. **Unpredictable adoption triggers at the end users' side poorly suit the need for long term planning at the suppliers' side:** Supply chain actors report poor strategic planning by end users, especially underestimating the time and difficulty of securing grid connections amid congestion. From the end users' perspective, however, heat-pump adoption is often triggered by unexpected external changes that create sudden investment windows.

2. **Risk perceptions, technological complexity, and resistance to change jointly prevent investment in heat pumps by end users.** Novel heat pump applications are widely perceived by end users and suppliers as complex, risky, and insufficiently proven, especially given long payback times compared to alternatives. Suppliers interpret this as resistance to change, while end users seek evidence from real-world operation. The lack of (widely known) pilots reinforces risk perceptions, often rooted in organisational cultures that prioritise production continuity and proven technologies, particularly in the food and beverage sector.

3. **Distrust between end users, technology suppliers and energy advisors may hamper heat pump business case development and implementation.** Trust between actors strongly shapes heat pump adoption, with low trust hampering communication, increasing risk perceptions, and delaying projects, while high trust can help advance complex or time-critical investments. Longstanding collaborations may reduce uncertainty and enable rapid action when external conditions change. However, some end users remain sceptical of energy advisors, questioning their added value due to complex production processes and a preference for independence from outsiders.

Recommendations to address the above challenges include:

1. **Develop a program for systemically de-risking industrial heat pumps to attenuate risk perceptions.** The program may have a twofold focus on (1) developing heat pump showcases and (2) creating awareness of ongoing showcases. Financial support for such initiatives, as well centralising communication through a central service desk (e.g. an enterprise agency), may be needed to ensure their creation and success.

   The program should also foster cross-domain knowledge exchange to equip engineers with the skills to apply heat pump concepts to various use cases, sectors, and companies. For example, SMEs involved in heat pump development could be supported by funding for attending conferences focused on such knowledge exchange.

   Given the importance of knowledge sharing to reducing perceived investment risks, funding agencies should consider granting subsidies only when showcase activities take place. They should also investigate how end users' fears around showcasing can be alleviated, by setting conditions on attendance, setting, or scope of the showcase.

2. **Build enduring partnerships between end users, suppliers, and energy advisors to foster trust.** Enduring partnerships may be kickstarted by developing Collaborative Business Models (CBMs) that focus on shared value creation. An example of a CBM is a building team (in Dutch: 'bouwteam') where contractors, end users and technology suppliers jointly integrate the heat pump into the production process. A building team focuses on collaborative design instead of a strict division of responsibilities across the various steps in heat pump integration.

   Trusted partners, such as Energy Service Companies (ESCo's), could stimulate the uptake of these approaches by creating awareness among their clients about their potential benefits. Network organisations (e.g. the European Heat Pump Association; EHPA), industry organisations (e.g. FNLI, VNCI or MKB Nederland in the Netherlands) and enterprise agencies (e.g. RVO in the Netherlands) can offer training modules in these approaches, as they are already commonly the first point of contact for suppliers and end users for advice on regulations and subsidies.

3. **Develop training programs to reduce the skills gap.** Existing information channels are insufficient for bridging the skills gap, necessitating a more coordinated approach through targeting specific regions or clusters, and taking advantages of potential synergies of between industrial facilities. Such a coordinated program may include (1) EU-wide certifications and training programmes for engineers and technicians in industrial sectors, (2) resources to re-train contractors and installers and (3) investments in vocational and university programs for sustainable heating technologies, as well as on-the-job-training.

Samenvatting

Industriële warmtepompen kunnen voorzien in de industriële vraag naar lage-temperatuurwarmte, die wordt opgewekt zonder gebruik te maken van fossiele brandstoffen. Nederlandse en Europese overheden zetten zich in voor deze technologie, met name voor de levering van lage-temperatuurproceswarmte (<200 °C).

Toch is de adoptiegraad van warmtepompen laag. Na jaren van gestage groei daalde de totale verkoop van warmtepompen in de EU in 2023 en 2024, gevolgd door een beperkte opleving in 2025. Deze groei concentreert zich in de gebouwde omgeving, terwijl adoptie in de industrie beperkt blijft. Bij het huidige groeitempo is het onwaarschijnlijk dat de huidige ambities op het gebied van energiezekerheid en klimaat worden gehaald.

Technische en niet-technische belemmeringen staan adoptie in de weg. Hoewel er op grote schaal commerciële oplossingen beschikbaar zijn voor industriële warmtepompen voor lage temperaturen tot 120 °C en 10 MW, komen oplossingen voor hogere temperaturen of grotere capaciteiten ofwel pas net op de markt (voor 120-160 °C), of bevinden ze zich nog in de demonstratiefase van ontwikkeling (>160 °C). Op ecosysteemniveau zijn verschillende niet-technische uitdagingen (bijv. hoge investeringskosten, ongunstige prijsverhoudingen tussen gas en elektriciteit, netcongestie) geïdentificeerd die snellere adoptie in de weg staan. Deze uitdagingen zijn al uitgebreid aan de orde gekomen in eerdere studies en worden al aangepakt in bestaande EU- en Nederlandse beleidskaders.

Gegevens over concrete implementatietrajecten bij eindgebruikers ontbreken in bestaand onderzoek naar niet-technische belemmeringen. Hoewel bestaande studies veelvoorkomende belemmeringen op het niveau van het innovatie-ecosysteem belichten, ontbreekt het aan gedetailleerder inzicht uit specifieke casussen met betrekking tot het daadwerkelijke ontwikkelings- en implementatieproces. Dit onderzoek richtte zich daarom op twee niveaus: de toeleveringsketen en het project (d.w.z. één enkel implementatietraject bij één enkele eindgebruiker). De belemmeringen werden in kaart gebracht door middel van interviews en workshops met actoren in de toeleveringsketen voor warmtepompen en vier casestudies van invoeringstrajecten van warmtepompen bij bedrijven in de voedingsmiddelen- en papierindustrie.

Op het niveau van de toeleveringsketen belemmert een gebrek aan opleiding in het combineren van kennis over warmtepompen en productieprocessen de integratie van warmtepompen in bestaande processen. Deelnemers in de toeleveringsketen zagen het gebrek aan opleiding in warmtepomptechnologie voor ingenieurs en industriële technici als een belangrijke barrière, evenals specifieke opleiding voor koeltechnici om hun kennis af te stemmen op industriële warmtepompen (bijvoorbeeld over natuurlijke koelmiddelen). Het gebrek aan gecombineerde kennis van zowel elektrische verwarmingstechnologie als productieprocessen wordt in de literatuur erkend als een belangrijke barrière voor industriële elektrificatie.

Op projectniveau kwamen drie uitdagingen naar voren:

1. **Onvoorspelbare adoptieprikkels bij eindgebruikers sluiten slecht aan bij de behoefte aan langetermijnplanning bij leveranciers:** spelers in de toeleveringsketen melden gebrekkige strategische planning bij eindgebruikers, met name wat betreft het onderschatten van de tijd en de moeilijkheidsgraad om netaansluitingen te verkrijgen tijdens netcongestie. Vanuit het perspectief van de

eindgebruikers wordt de invoering van warmtepompen echter vaak gestimuleerd door onverwachte externe veranderingen die plotselinge investeringskansen creëren.

2. **Risicopercepties, technologische complexiteit en weerstand tegen verandering vormen samen een belemmering voor investeringen in warmtepompen door eindgebruikers.** Nieuwe toepassingen van warmtepompen worden door eindgebruikers en leveranciers algemeen gezien als complex, risicovol en onvoldoende beproefd, vooral gezien de lange terugverdientijden in vergelijking met alternatieven. Leveranciers interpreteren dit als weerstand tegen verandering, terwijl eindgebruikers op zoek zijn naar bewijs uit de praktijk. Het gebrek aan (algemeen bekende) proefprojecten versterkt de risicopercepties, die vaak geworteld zijn in organisatieculturen die prioriteit geven aan productiecontinuïteit en beproefde technologieën, met name in de voedingsmiddelensector.

3. **Wantrouwen tussen eindgebruikers, technologieleveranciers en energieadviseurs kan de ontwikkeling en uitvoering van businesscases voor warmtepompen belemmeren.** Vertrouwen tussen de betrokken partijen is van grote invloed op de adoptie van warmtepompen: een laag vertrouwen belemmert de communicatie, vergroot de risicoperceptie en vertraagt projecten, terwijl een hoog vertrouwen kan helpen bij het realiseren van complexe of tijdgevoelige investeringen. Langdurige samenwerkingsverbanden kunnen onzekerheid verminderen en snelle actie mogelijk maken wanneer de externe omstandigheden veranderen. Sommige eindgebruikers blijven echter sceptisch ten opzichte van energieadviseurs en twijfelen aan hun toegevoegde waarde vanwege complexe productieprocessen en een voorkeur voor onafhankelijkheid van externe partijen.

Aanbevelingen om de bovengenoemde uitdagingen aan te pakken zijn:

1. **Ontwikkel een programma om de risico's van industriële warmtepompen systematisch te verminderen en zo de risicoperceptie te temperen.** Het programma kan een tweeledige focus hebben op (1) het ontwikkelen van showcases met warmtepompen en (2) het vergroten van de bekendheid van lopende showcases. Financiële steun voor dergelijke initiatieven, evenals het centraliseren van de communicatie via een centrale helpdesk (bijvoorbeeld een ondernemersagentschap), kan nodig zijn om de totstandkoming en het succes ervan te waarborgen.

   Het programma moet ook domeinoverschrijdende kennisuitwisseling bevorderen om ingenieurs de vaardigheden bij te brengen om warmtepompconcepten toe te passen op diverse gebruikssituaties, sectoren en bedrijven. Zo zouden bijvoorbeeld kleine en middelgrote ondernemingen die betrokken zijn bij de ontwikkeling van warmtepompen ondersteund kunnen worden door financiering voor het bijwonen van conferenties die gericht zijn op dergelijke kennisuitwisseling.

   Gezien het belang van kennisdeling voor het verminderen van de waargenomen investeringsrisico's, zouden financieringsinstanties moeten overwegen om alleen subsidies te verlenen wanneer showcases plaatsvinden. Zij zouden ook moeten onderzoeken hoe de bezorgdheid van eindgebruikers rond showcasing kan worden weggenomen, door voorwaarden te stellen aan de deelname, de opzet of de reikwijdte van de showcase.

2. **Bouw duurzame partnerschappen op tussen eindgebruikers, leveranciers en energieadviseurs om vertrouwen te bevorderen.** Duurzame partnerschappen kunnen op gang worden gebracht door het ontwikkelen van collaboratieve business modellen (CBM's) die gericht zijn op het creëren van gedeelde waarde. Een voorbeeld van een CBM is een bouwteam waarin aannemers, eindgebruikers en

technologieleveranciers gezamenlijk de warmtepomp in het productieproces integreren. Een bouwteam richt zich op gezamenlijk ontwerp in plaats van een strikte verdeling van verantwoordelijkheden over de verschillende stappen bij de integratie van warmtepompen.

Trusted partners, zoals Energy Service Companies (ESCo's), zouden de adoptie van deze benaderingen kunnen stimuleren door hun klanten bewust te maken van de potentiële voordelen ervan. Netwerkorganisaties (bijv. de European Heat Pump Association; EHPA), brancheorganisaties (bijv. FNLI, VNCI of MKB Nederland in Nederland) en ondernemersagentschappen (bijv. RVO in Nederland) kunnen opleidingsmodules over deze benaderingen aanbieden, aangezien zij doorgaans al het eerste aanspreekpunt zijn voor leveranciers en eindgebruikers voor advies over regelgeving en voor subsidies.

3. **Ontwikkel opleidingsprogramma's om de vaardigheidskloof te verkleinen.** De bestaande informatiekanalen volstaan niet om de vaardigheidskloof te overbruggen; daarom is een beter gecoördineerde aanpak nodig, waarbij specifieke regio's of clusters worden aangepakt en gebruik wordt gemaakt van mogelijke synergieën tussen industriële faciliteiten. Een dergelijk gecoördineerd programma kan het volgende omvatten: (1) EU-brede certificeringen en opleidingsprogramma's voor ingenieurs en technici in industriële sectoren, (2) middelen voor de omscholing van aannemers en installateurs, en (3) investeringen in beroeps- en universitaire opleidingen voor duurzame verwarmingstechnologieën, evenals praktijkgerichte opleidingen.

Contents

1 Introduction

To support the decarbonisation of industry, industrial heat pump adoption needs to expand. The decarbonisation of Europe's industries is a key component – next to strengthening these industries' competitiveness - of the upcoming Industrial Accelerator Act (IAA) (European Commission, 2026). One of the problems the act aims to address is the delay in deployment and scale up of new technologies. One of these new technologies, industrial heat pumps, has the potential to meet the industrial demand for low temperature heat generated without using fossil fuels. Heat pumps are therefore an attractive decarbonisation option for such industries as food and beverage, paper and pulp and textiles.

In the Netherlands, industrial heat pumps (<100°C) may save up to 35.3PJ in natural gas consumption through their application at companies located in business parks, primarily in these sectors (TNO, 2024). The Dutch government aims to accelerate (industrial) heat pump uptake – as well as other technologies for industrial electrification – through the action agenda electrification (Ministerie van Klimaat en Groene Groei, 2025). The action agenda specifies actions for improving policy consistency, financial incentives, innovation and knowledge sharing and the flexible operation of assets. Within the action agenda, the industrial heat pump is explicitly selected as the preferred technology for supplying low temperature process heat (<200°C).

Yet, the current heat pump adoption rate is low. After years of steady growth, overall EU heat pump sales declined in 2023 and 2024 (EHPA, 2025b), followed by a limited boost in 2025 (EHPA, 2026a). Overall heat pump sales in the Netherlands follow a similar pattern (DNE Research, 2026), while only a handful of industrial heat pump projects have been realised, primarily through the stimulus policy for renewable energy (SDE++) (RVO, 2026). At the current growth rate, current energy security and climate ambitions are unlikely to be met (EHPA, 2026a).

Technical issues hamper industrial heat pump adoption. Although commercial solutions for low temperature industrial heat pumps are widely available up to 120°C and 10MW, solutions at higher temperatures or larger capacities are either only just entering broader commercial availability (for 120-160°C) or still in the demonstration phase of development (>160°C)(IEA Heat Pump Centre, 2025). Hence, further technological development is necessary to enable the use of heat pumps for applications needing higher temperatures. Some of this development work is undertaken in other work packages within the Kickstart project[1].

Adoption may also be hampered by non-technical barriers. Heat pumps that are commercially widely available may still be confronted with non-technical adoption barriers. These non-technical barriers range from economic barriers (e.g. high capital costs and unattractive gas to electricity price ratios) to infrastructure (e.g. grid congestion) and knowledge (e.g. lack of skills for integration, lack of knowledge sharing) barriers. These non-technical barriers have been studied extensively, both for industrial electrification

[1] The KickStart project aims to develop and demonstrate two repeatable heat pump concepts integrated in running processes (brownfield application) and develop five repeatable concepts for heat pump integrated processes (green field). For further information on the KickStart project, see [Kickstart market industrial heat pumps - Topsector Energie]

technologies in general (e.g. Rosenow et al., 2025) and industrial heat pumps specifically (Aydemir et al., 2026; Copernicus Institute of Sustainable Development & ISPT, 2019; EHPA, 2026b; Wesseling et al., 2022).

Studies into non-technical barriers lack data on concrete adoption trajectories at end users. Although these studies highlight common barriers at the level of the innovation ecosystem[2], they lack more detailed insight from specific cases regarding the actual development and implementation process. For example, they miss insights that illustrate what barriers technology suppliers and end users run into while (attempting to) explore options for meeting their heat demand; barriers to developing a business case for a heat pump, or barriers to integrating the heat pump into their production process. As a result, these studies tend to overlook adoption barriers at the level of the supply chain or the project. Yet, these barriers commonly hamper investments in energy efficiency at companies (Kooger, 2018).

The aim of this study is to identify the non-technical barriers to heat pump adoption, as well as develop solutions for tackling these barriers. This report supplements existing studies by elucidating barriers at the level of the supply chain and project. To this end, we have conducted interviews and workshops with actors in heat pump supply chain and four case studies of heat pump adoption trajectories at companies in the food and paper industries. The workshops and case studies focused on companies with an operating presence in the Netherlands. The range of non-technical barriers identified throughout these activities was used to develop recommendations for policy makers and other actors in the heat pump innovation ecosystem. These recommendations primarily focus on tackling barriers to collaboration between technology suppliers, end users, and energy advisors, as recommendations for common ecosystem level barriers are extensively covered elsewhere.

This study was conducted as part of the Kickstart project[1]. The KickStart project is an RVO funded project within the MOOI-scheme. The project aims to accelerate the implementation of industrial heat pumps by developing technological solutions as an alternative to fossil fuel fired heating systems and by identifying non-technical barriers to industrial heat pump adoption.

Outline of the report

- **Chapter 2:** Brief explanation of industrial heat pumps and their supply chain.
- **Chapter 3:** Results of the four case studies (3.1) and supply chain interviews and workshops (3.2).
- **Chapter 4:** Summary and discussion of barriers identified in the case studies, interviews and workshops, contextualised in the existing literature.
- **Chapter 5:** Recommendations for tackling barriers at the supply chain and project levels.
- **Appendix A:** Details on the research method that was applied in the study (interview protocols and workshop contents)
- **Appendix B:** Detailed output of the supply chain workshops and interviews.

[2] Here we define the innovation ecosystem based on the technological innovation systems literature as “network(s) of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse, and utilize technology” (Carlsson & Stankiewicz, 1991, p.111).

2 Industrial heat pumps in context: technology, actors, and competition

2.1 What are industrial heat pumps and how do they work?

Industrial heat pumps offer an option for the decarbonisation of low temperature industrial heat demand (<200°C). Heat pumps can upgrade the temperature level of a waste heat source to the level of a given process with input of electrical energy. In this way, the reuse of waste heat in the process is possible, resulting in large savings in energy consumption and associated CO_2 emissions. With the increasing share of renewable electricity generation, utilising an industrial heat pump powered by electricity is a robust choice for achieving a more sustainable industry. More specifically, the implementation of heat pumps could result in both significant energy efficiency improvements as well as the uptake of a sustainable energy source (depending on the grid energy mix in question). It is a cross sectoral technology that is suited for both retrofit, i.e. brownfield and in new factories, i.e. greenfield applications.

A simplified comparative energy flow diagram for two industrial processes can be seen in Figure 2.1, one which uses a fossil fuel source and another which uses a heat pump for the process heating requirements. The process driven by fossil fuels requires 110 % of the heat required by the process, as approximately 10% of the energy is lost after combustion to the ambient in flue gases. None of the waste heat is recovered, meaning all of the process heat is released too ambient.

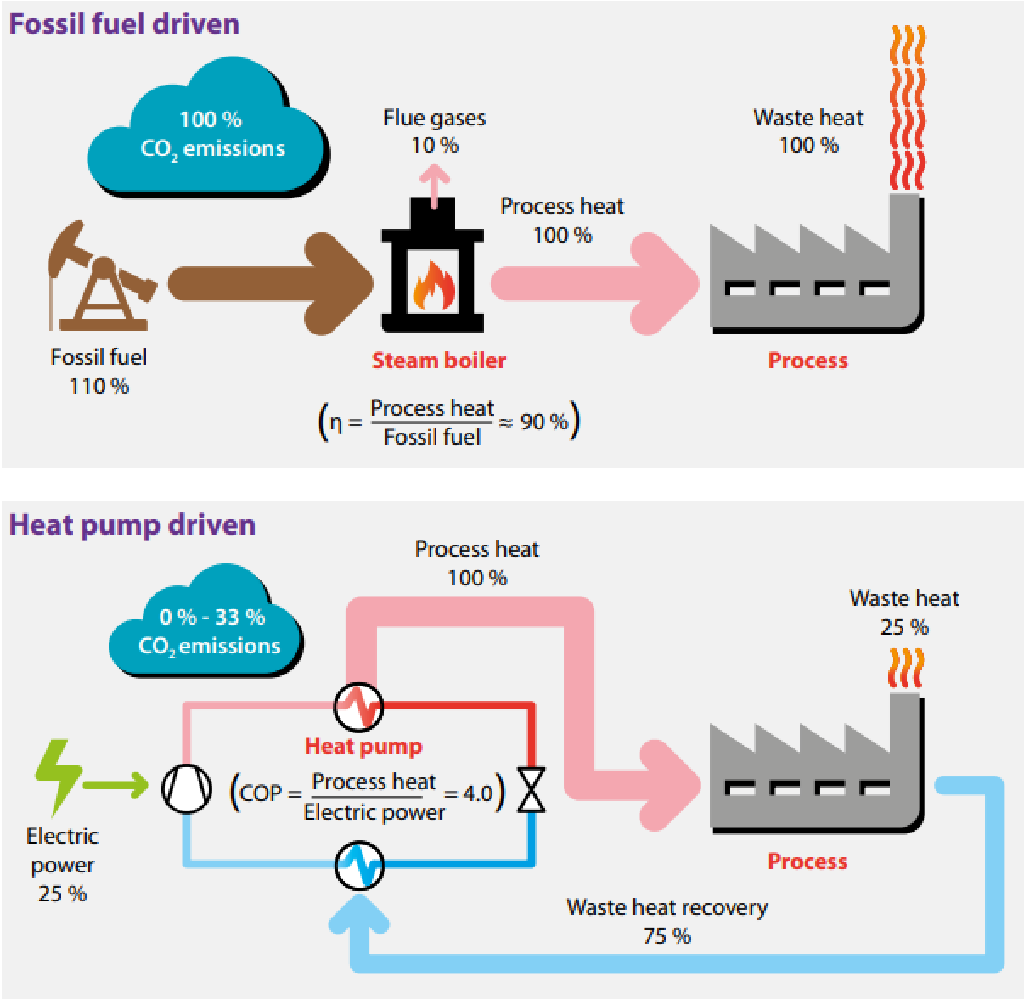

Figure 2.1: Comparison of fossil fuel driven and heat pump driven industrial process schemes (de Boer et al., 2020).

For the process using a heat pump, the waste heat discarded to ambient is reduced to 25% of the process heat supply. With 75% of the total waste heat reused by upgrading the temperature level with the heat pump, the process heat delivered (100%) exceeds the electricity input (25%) by a factor of 4. This value, i.e. the ratio of the heat delivered, to the electricity input, is known as the coefficient of performance (COP) and is an important parameter characterizing the efficiency of the heat pump. This value will usually be in the range of 2 to 5, depending on the temperature of the waste heat and the requirements of the process heat. Therefore, rather than simple use and disposal of energy in the original process, implementing a heat pump achieves a large degree of energy circularity, increasing the overall efficiency of the process. A higher COP results in a lower electricity consumption for a given heat pump application.

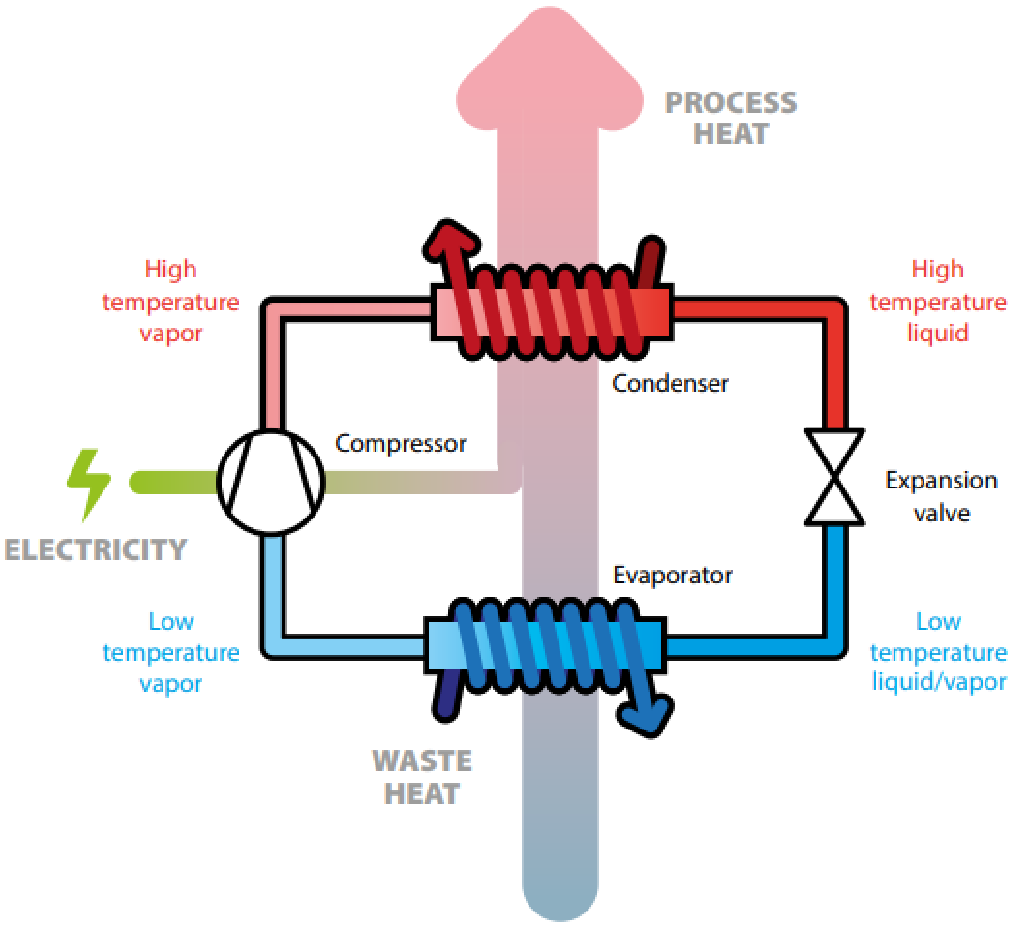

Figure 2.2: Technical process layout of a vapor compression heat pump with the energy flow depicted (de Boer et al., 2020).

Figure 2.2 presents a simplified scheme of the technical process of the most commonly applied heat pump technology: a vapor compression heat pump. To upgrade energy from waste heat into process heat, a refrigerant (or working fluid) is used within the system. This refrigerant undergoes various processes and state changes as it moves through different components. In the evaporator, which is the part of the system with the lowest temperature and pressure, waste heat is absorbed by the refrigerant, changing it from mostly liquid to vapor. This vapor is then compressed to a high pressure and temperature by the compressor, which requires mechanical work and thus electrical input. The high-pressure, high-temperature vapor then releases heat for use in the process within the condenser, turning the refrigerant back into a liquid. The high-pressure liquid refrigerant is then reduced to a low pressure and temperature by an expansion device, re-entering the evaporator and repeating the cycle (de Boer et al., 2020)

In Europe, the majority of heat pumps are used for low-temperature processes (below 100 °C), which are predominantly deployed in the paper, food and chemicals industries (EHPA, 2023a). There is significant market potential for industrial heat pumps in Europe. A TNO-market study estimated there are up to 3229 units could be supplied up to 150°C in the paper, chemicals, food and refinery sectors; and, up to 4174 units up to 200°C (Marina et al., 2021). Despite the availability and potential of the technology, it is currently not utilized extensively by the industry. Even for new capacity and applications at these low temperatures, fossil fuel fired process heating equipment is the standard.

Overall, the European market for <100 °C is around 10% of the total process heat. For the market segment of the temperature range of 100 °C to 200 °C, products and technical solutions still have to be developed and demonstrated, see Table 2.1 for a simplified overview of the technology readiness levels per temperature range. Heat pumps developed for this market have much higher potential than the technical solutions already developed for <100 °C. Prototypes are operating at around 180 °C with expectations of projects of 200 °C and beyond in the coming decade.

Table 2.1: A simplified overview of temperature ranges, technological readiness levels and examples process applications for industrial heat pumps (EHPA, 2023a; International Energy Agency, 2022).

Temperature range	Technology readiness level	Example process
<80 °C	TRL 11: Proof of market stability	Paper: De-inking Food: Concentration Chemicals: Bio-reactions
80 °C – 100 °C	TRL 10: Commercial and competitive, but large-scale deployment not yet achieved.	Paper: Bleaching Food: Evaporation Chemical: Boiling
100 °C – 140 °C	TRL 8-9: First of a kind commercial application in relevant environments	Paper: Drying Food: Evaporation Chemical: Concentration
140 °C - 160 °C	TL 6-7: Pre-commercial demonstration	Paper: Pulp boiling Food: Drying Chemical: Distillation Various industries: stream production
160 °C -200 °C	TRL 8-9: First of a kind commercial application for small scale MVR systems and heat transformers TRL 4-5: early to large prototypes	Various industries: high temperature stream production
>200 °C	TRL 4: Eary prototype	Various industries: high temperature processes

2.2 The key actors in the industrial heat pump supply, installation, and maintenance

There are many actors involved in the supply, installation, and maintenance of an industrial heat pump. The European heat pump sector is a growing industry, with many people involved in R&D, manufacturing, installation, and maintenance[3]. Figure 2.1 provides a non-exhaustive overview of the actors within the supply chain of an industrial heat pump. This figure shows the supply chain for a brownfield application.

[3] Information about the size of the market is only available for domestic heat pumps (250 manufacturing sites in Europe, 168.000 direct jobs), for the industrial market the EHPA is gathering data (EHPA, 2024).

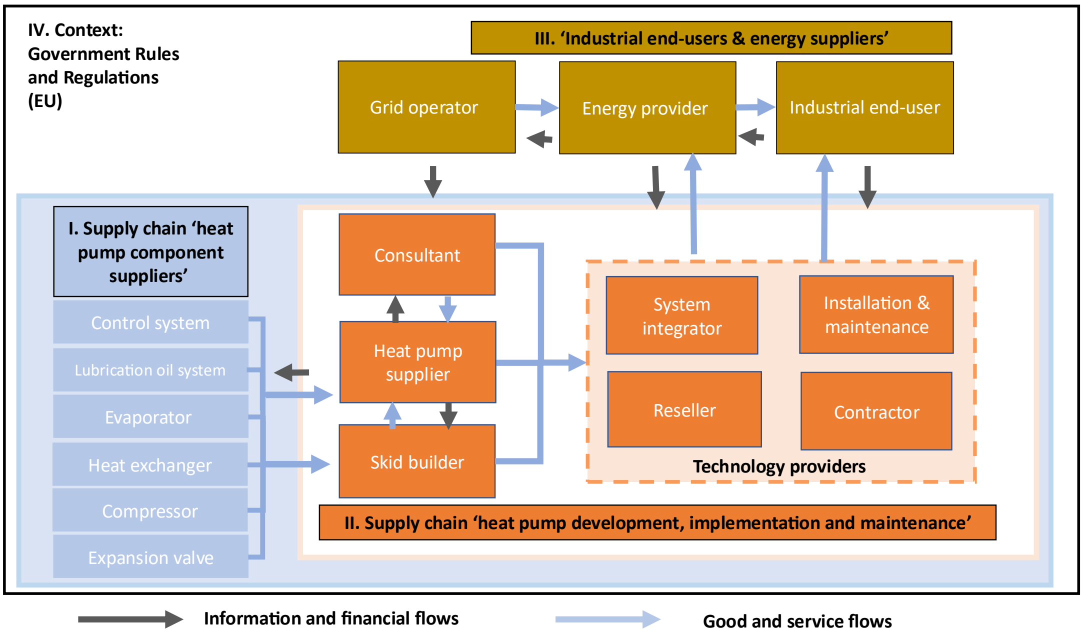

Figure 2.1: The supply chain for industrial heat pump for a brownfield application. The fundamental difference between a green and brownfield supply chain, is a greenfield project will also include the process equipment supplier, i.e. the companies supply the industrial processing technology, such as a paper pulping machine or industrial refining equipment (source: TNO own creation).

The **'heat pump component suppliers'** refers to companies involved in supplying the key components for the delivery of a high-temperature compression heat pump. This map shows the most important components includes, among others, the heat exchangers, expansion valve, control system, and the compressor. The compressor is the key component in the system, with its performance and cost strongly correlated to that of the overall heat pump system; however, there are currently few companies that can supply the compressor up to and beyond 160°C (Boer et al., 2020). Moreover, many industrial heat pump components are not available "off the shelf" as higher temperatures and process-specific requirements often mean that that is no serial production. Therefore, individual pieces of equipment must be selected or developed. Suppliers are constantly engaged in R&D to improve performance.

The **'heat pump development, implementation and maintenance'** are all those involved in the interface with the end user, including the development, implementation, and maintenance of the heat pump solution. These are the consultants who advise on solutions or provide an energy balance or pinch analysis; those actors providing the heat pump technology and assembly, e.g., technology suppliers and skid builders; and those who design and deliver the system and engineering solutions to the end user, e.g., the system integrators, reseller, contractor and installation and maintenance company. System integrators build new 'systems' by integrating old ones with new, e.g. a heat pump into a paper-producing process for a brownfield application. A reseller purchases or resells specific industrial components and provides expertise on them. Contractors deal with specialized facilities and provide the design, installation, and maintenance of mechanical or structural components of industrial facilities. Installation & maintenance companies provide installation and maintenance services and can either be a division within the end user or a separate organization. Depending on the project, many companies can perform multiple roles within the supply chain.

The '**industrial end user'** is the eventual user of the industrial heat pump, and the customer to the rest of the supply chain. Most of the industrial process heat is currently generated by burning natural gas. The shift to a heat pump, also supplied by green electricity, will require long-term planning for their connection to the national grid and reliable electricity supply.

The last segment is the **'context'** in which this industrial value chain operates. This includes general market trends and prices. In addition, the government (EU and member state) provide the rules and norms in which companies operate, including (but not limited to) the incentives for heat pump installation, support for R&D and educational programmes for the training of skilled engineers. This is the context which can further shape the shift away from fossil fuels and towards green solutions.

2.3 Industrial heat pumps competition: the example of e-boilers

Decarbonisation efforts will require a range of socio-technological solutions, which vary depending on the industrial sector in question. A review of energy efficiency options for Dutch industry indicated the varying measures available for fertilizer, iron and steel, chemicals, paper, refineries and other industries (PBL & TNO, 2023). Nevertheless, industrial heat pumps will not be a universal decarbonisation solution and will also have to compete with other technologies.

One such technology that is in competition with industrial heat pumps are e-boilers. Instead of using gas as its means to create heat or steam, an e-boiler uses electricity, which, if supplied from renewable energy sources provides a concrete decarbonisation option for industrial end users. There is no definitive scientific consensus of which technology is the most suitable for specific industrial sectors, which each having various arguments in favour. Here we summarise the main arguments used by market parties for each technology. Proponents of e-boilers argue that compared to industrial heat pumps they are less costly (in terms of capital costs and payback time), have lower maintenance costs, and have an easier installation process[4]. In a hybrid set-up, i.e. with other heat generation types such as gas boilers, they offer flexibility and can be quickly switched on or off to supply heat or steam depending on electricity pricing[5]. Conversely, industrial heat pump advocates indicate that they are much more efficient than e-boilers and consequently are cheaper over a longer period; while industry payback times are typically one to two years, they can be extended to two to five under certain circumstances. Such a timeframe would fit an industrial heat pump[6].

[4] For examples, see: Switch to industrial electric boilers - Action Library; Electric boiler VS heat pump: what to choose? - ThermoGroup

[5] For examples of industry proponents of them see Electric steam boilers: applications of electric boilers in industry - Heating Group International B.V.; or E-boiler BECC delivers within 30 seconds

[6] For examples, see: wp-jci-iref-district-energy-white-paper-062021.pdf; Heat pump vs boiler | Which wins? | Aspiration Energy; Exploring the pros and cons of electric boilers - Adven; 2020-07-10-whitepaper-ihp-a4.pdf

3 Results: Non-technical adoption barriers

In this chapter, the results of the interviews and workshops conducted throughout the project are discussed. Chapter 3.1 describes the results from interviews conducted in four heat pump adoption cases, focused on the barriers that end users, suppliers and energy advisors (if any were involved) experienced during the adoption process. Chapter 3.2.1 elucidates the barriers discussed by heat pump supply chain actors across various heat pump adoption processes, relating both to barriers experienced between companies in the supply chain, as well as barriers experienced in their collaboration with end users of heat pumps. Chapter 3.2.2 discusses results from workshops conducted with supply chain members on the strengths and weaknesses of the supply chain, as well as opportunities and threats to the supply chain's further development.

3.1 Case studies of heat pump adoption

Four case studies were conducted to identify non-technical barriers to the adoption of industrial heat pumps, focusing primarily on the collaboration between end users, technology suppliers, and energy advisors. The four cases cover a range of plant types (greenfield, brownfield), heat pump applications (temperature changes, refrigerants) and company types (size, sector, status of sustainability strategy and KPIs) (see Table 3.1 for key case characteristics).

Table 3.1: Key characteristics of the four cases

	Case A	Case B	Case C	Case D
Sector	Food	Food	Food	Paper
Production plants	15	4	28	36
Site location	Netherlands	Netherlands	Netherlands	Czech Republic
Site type	Brownfield (pilot)	Brownfield	Greenfield	Brownfield (pilot)
Adopted technology	Heat pump 75-90°C	Gas and hybrid boiler for steam production	Heat pump 70°C (CO_2 refrigerant)	Intention to adopt heat pump 110-150°C – project on hold
Adoption trigger	Maintenance window; pilot for new greenfield location	Upcoming contract renewal for steam from supplier (higher price)	Major accident in plant requiring new plant to be built	Site was selected as pilot for participation in EU research project
Formal sustainability strategy	Yes, part of SBTI.	No	Under development	Yes
KPIs	Energy (ISO 50.001), CO_2	Energy (ISO 50.001)	Under development	Energy (ISO 50.001), CO_2

Each case covers a single adoption process for an industrial heat pump; some processes led to heat pump adoption (A, C), while others did not (B), or were on hold at the time of the study (D). The adoption process each case went through, including the status at the time of the study, are reported in Figure 3.1.

Each case had a distinct adoption trigger; a (sudden) change in external or external conditions that triggered the start of heat pump business case development. In all cases, the financial viability of the business case was mentioned as a key driver for continuing the adoption process, with subsidies commonly playing a key role in securing a viable business case (C, D). The additional drivers that were mentioned by interviewees differed between the cases:

- Piloting heat pumps (A) to develop knowledge, manage risks and kickstart a gradual roll-out (D)
- Innovativeness and openness to risk (A)
- KPIs (for CO_2 emissions) (A)
- Changes to senior management (A)
- Advantageous price developments (A)
- Customer pressure (C)
- Proactive attitude (C)

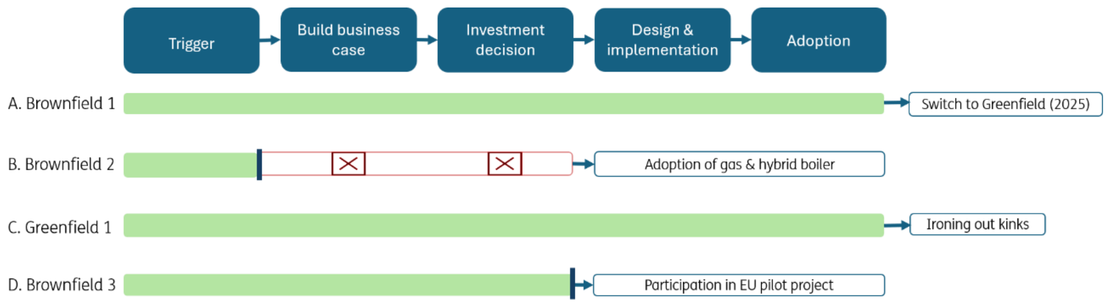

Figure 3.1: Adoption stages for the four cases.

In the following section the adoption process of each of the four cases is described, including its trigger, primary motivation and barriers experienced during the adoption process. In the interview quotes provided, additions by the research team to improve readability or obscure sensitive company details are noted in square brackets.

3.1.1 Case A

For company A, interviews were conducted with the global environmental director, director global engineering, global manager process engineering, technology supplier, and alternative technology supplier.

The adoption trigger at company A was upcoming maintenance (i.e. replacement of the cooling unit) providing an opportunity to add a heat pump (75-90°C) to the production process:

> *"…an investment was coming up for a new cooling installation. Renewing the cooling installation provided momentum for taking an extra step to connect a heat pump with our process. You really need to have an incentive to do so and that was not there before. Then it would have been an isolated investment and then it becomes very difficult." (director global engineering company A)*

The adoption process started as a bottom-up initiative, requiring substantial time and effort from the local engineering team:

“So, this is something that we really did a little bit on the side. Because the management was not pushing to get a heat pump. It was really coming from the bottom, like happens many times, so this is a normal way of working.” (global manager process engineering company A)

The engineers responsible for developing the heat pump concept also positioned the investment as a **pilot** (location A), helping the investment in getting funding from senior management:

“And also there was this piloting, to say, this is proven technology outside [Company A], but is not a proven technology proven in [Company A], but this heat pump can even be utilised in the new location, in the new [Location B] factory, so it is not an investment that will just die together with [Location A]. So, we can bring it towards the future and maybe there will be even more. So, we positioned it that way.” (global manager process engineering company A)

Company A viewed starting the pilot in a specialties plant as advantageous, due to location A’s different attitude toward **innovation** and **risk**:

“It is not a surprise that this heat pump has been first installed in a specialty business. A little bit what I told you. We are not so afraid of risk, so we are happy to innovate. But in all [Company A] there are [mentions number] factories, there is no heat pump.” (global manager process engineering company A)

Despite the location’s apparent attractiveness for a pilot, getting senior management on board for the investment took years of concept development and several iterations of business cases. Initially, management was concerned about **risks** to production continuity and unconvinced by **the payback time**:

“Because maybe they were touching part of the process that is too critical, we don’t want to have any disturbances, or maybe because the payback was not very interesting, so it was many times refused by the first layer, basically by the plant manager, who said ‘I don’t want to have this problem’.” (global manager process engineering company A)

One of the triggers for an eventual approval from senior management was company A’s adoption of the Science Based Targets initiative and accompanying **KPIs for CO_2 emissions** for the local management team:

“We got endorsement from the company to work towards sustainability. Reducing CO_2 emissions, our energy footprint. So, this came as a push. So, the plant manager started to get more interested: ‘OK, this is not just crazy engineering, it is also improving my score card’.” (global manager process engineering company A)

“I think, this was a very important step we made, and this was I think the biggest trigger. This also triggered the senior management to accept this type of challenge, to give resources, to give space.” (global manager process engineering company A)

Other factors that may have contributed to the investment decision were a **change in the senior management team**, as well **advantageous price developments** for heat pumps, although interviewees did not fully agree on the influence of these factors:

“But of course, we had, the [mentions senior manager] we call it, was really not caring at all, also personally, it was not something touching him. Also coming from a different country, coming from [country X], in [country X] the visibility of this topic is very different. So that

person changed, he changed role, a new person came, with [another] background, and he was very positive, so he said 'ok, let's go, let's try'." (global manager process engineering company A)

"I am convinced that, in our situation, we would not have any problems making the [business] case again and getting it to function another time, due to the current price developments, but also the CO_2 goals of the company. Of course, it is always somewhat dependent on the people themselves and also on the engineers…. That's the problem with these issues, right? Everyone thinks it is important, but it is never urgent" (director global engineering company A)

Company A has now adopted a heat pump in location A that will be in operation for the next few years. This pilot will also be used to inform development of a heat pump concept for a greenfield location that is still to be developed (and will be replacing the brownfield location A).

3.1.2 Case B

For company B, interviews were conducted with the assistant plant manager, business developer and the heat pump supplier involved in adoption process.

The adoption trigger at company B was an **upcoming contract renewal** with a neighbouring company supplying steam for the business park company B is located in (the business park was constructed without a natural gas grid connection). Company B considered the imposed contract conditions so unfavourable (i.e. higher price) that – combined with unfavourable prices and supply insecurity for natural gas as a result of the Ukraine war - they decided to examine alternatives for producing their own steam (110°C), including installing a heat pump, an e-boiler and using hydrogen. A heat pump supplier then conducted business case calculations for a heat pump, which were perceived as unfavourable by company B (just like the business case for an e-boiler and for using hydrogen). Company B's decision making was primarily financially driven (i.e. increases in production costs, investment budget required), but they also mentioned independence, limiting production risks and customer pressure as key factors for investment.

Financial drivers: "*The sustainable alternatives were so much more expensive that considering them was not realistic at the moment." (assistant plant manager, company B)*

Limiting production risks: *"Our primary condition is that we do not risk a standstill of our production process and that is a very important parameter when investigating certain technologies." (assistant plant manager, company B)*

Independence: *"So really reducing our dependence. Whether it is on energy, on customers, on suppliers or on people." Yes, we at company B are a little bit wary of that." (assistant plant manager, company B)*

Customer pressure: *"They (customers) have also completely woken up the past year, let's say. They will now just force you to be CO_2 neutral in 2040 or will otherwise not do business with you." (business developer company B)*

The supplier mentioned that building the heat pump business case was **complex** due to the novelty of the heat pump application and the difficulties in tracing the heat flows in the production process at company B. Despite these complexities, the business case process started from a position of **trust**:

"So that did give them some sort of trust. Ok, this is the party we should talk to and talk further with. But again, then you have to figure things out technically; could it even work? That is a very difficult puzzle." (supplier company B)

Company B recognized the inherent **complexity** of the heat pump application and expressed a need to see the heat pump application in practice:

"…but the step from hot water to steam; that was pretty complex. So, they still said, 'yes, those pumps are available'…. but I would like to see it in practice." (business developer company B)

Investing in **proven technology** – technology that can be seen working in practice - is important to company B:

""This (company B) is a family business, but we do not like the casino, so it needs to be proven technology." (business developer company B)

The supplier needed time to solve the complex heat pump puzzle. The time period was perceived as too long by company B, eroding their **trust** in the supplier:

"*…they were busy for a very long time…. It took so long that my trust in them started slipping, you know. At some point it stops, of course." (business developer company B)*

The erosion of **trust** and the **complexity** of the project, combined with **communication struggles** between the supplier and company B (about data needed for calculations), led company B to do their own business case calculations:

"*When I look at the time it cost to map it (heat flows), that is almost undoable for an outsider. Then someone will be walking around here for such a long time that the costs will become unrealistic." (assistant plant manager, company B)*

Company B's preference for **independence** – mentioned as one of their primary drivers – is also expressed in their perception of energy advisors:

"…I always prefer finding things out ourselves over energy advisors, because you will then be forced to …. think carefully about it." (business developer company B)

"(we) are pretty well informed on the market …what the impacts are on costs. Therefore, from my perspective, and I think we can say that was proven correct, it was not necessary to bring in an independent advisor." (assistant plant manager, company B)

Company B eventually adopted a natural gas boiler for producing steam that at the time of interviewing was not being used because they ended up renewing the contract with their steam supplier (with more favourable conditions).

3.1.3 Case C

For company C, interviews were conducted with the plant manager and chief engineer of company C, as well as the heat pump supplier and energy advisor.

The adoption trigger for company C was a major incident at one of their production locations. Due to the incident and company C's insurance conditions, a new plant had to be built and ready for operation within one year. Company C wanted to build a fully electric plant, leading them to investigate a heat pump delivering 70°C hot water using a CO_2 refrigerant. This investment was financially attractive due to **subsidy** opportunities for a certified fully electric plant:

"The subsidies you could receive for it played a major part in the decision, of course. That has been very important" (Chief engineer company C)

Company C's investment decision was also driven by their desire to **show customers** that they were making efforts at becoming more sustainable:

"…for our customers it is very important that we have made this decision. To cite our plant manager: 'we would really like to build the greenest (company C's product) factory of Europe'. That is sort of a strategic decision we have made as [company C]." (Chief engineer company C)

Company C also mentioned their **proactive attitude** as a major driver:

"By taking a proactive attitude, you will not be confronted with rules that are imposed on you by the authorities at a random moment, so we have always … had a proactive attitude toward this issue." (Chief engineer company C)

The heat pump application at company C was novel, requiring the supplier to **learn-on-the-job**:

"*…You will not find the installation we have here anywhere else, so in some ways things have been developed here that did not exist yet. Well, I think that required some learning from the supplier's side" (Chief engineer company C)*

Because of the project's novelty and strict timeline, company C opted for a supplier and energy advisor with whom they had already built **existing, positive relationships**:

"In these sorts of situations, you go back to companies with whom you have a good relationship and whom you think suit our challenges" (Chief engineer company C)

Yet the **novelty** of the heat pump application introduced challenges in the project's execution:

"The supplier committed to something they had never been able to realize yet. And came up with a state-of-the-art installation they had actually never built before. We had not foreseen that. But, in hindsight, that was 'mission impossible'. Maybe the supplier did not acknowledge that sufficiently." (Plant manager company C)

Some of the challenges were introduced by the use of CO_2 as a refrigerant, which was initially selected because the alternative (ammonia) required permitting, for which there was too little time in the project. Yet this refrigerant introduced several **technical challenges unforeseen** by the supplier:

"I think if the supplier had fulfilled their role, they would have said: "Stop, …. we cannot build this is in one year, we have never done so before." That stop never happened" (plant manager company C)

Other challenges were introduced by the project's **strict timeline**, requiring many activities to run simultaneously:

"We were still thinking about what the installation would look like. In the meantime, the contractor is asking: 'Just give me the weight of the … [mentions heat pump component] … because I have to order steel now, so please come by.' Yeah, bizarre." (supplier company C)

These challenges led to substantial **cost overruns,** as well as **reliability issues** and more **complicated maintenance** for the installed heat pump. Yet all of the interviewees expressed being content with the results of the project:

"…I think we are very content. We have a wonderful installation. In hindsight, I would have wanted to do a lot of things differently…. we are vulnerable in some ways, and the maintenance of the installation is not always simple." (plant manager company C)

At the time of interviewing, the heat pump was in operation at company C, and the supplier has been contracted to do maintenance and improvements on the heat pump.

3.1.4 Case D

For company D, interviews were conducted with the plant's energy engineer and operations manager (double interview) and managing director, as well the company's technical director and energy systems engineer (double interview), and the steam compressor supplier for the project.

The adoption trigger for company D was the possibility to participate in an EU pilot project for testing a steam compressor to use in a two-step heat pump process, raising the steam temperature from 110°C to 150°C. The primary reason for their participation in the pilot was to develop **knowledge** on the novel heat pump concept:

"It is not the case that we wanted a payback time there (in the project) of less than three years, we just want to see how…" (energy systems engineer company D)
"Does this concept work and does the idea work and then we would have to see where to bring it in" (Technical director company D)

Company D also mentioned that executing such a small-scale pilot helps them **reduce risk** for upscaling to larger plants:

"We prefer piloting in the smaller plants and not in larger plants because it is a certain risk that you take, that's why." (Technical director company D)

More specifically, company D expressed a strategy for **gradual roll-out** of (heat pump) concepts:

"We want to help make our companies better and, we call that 'develop blueprints', so just good ideas and if that is working in a plant, rolling it out to other factories. That is what we want" (Technical director company D)

Subsidies, or subsidized pilot projects, are important to company D to **manage risks** of developing new heat pump concepts:

"Our goal is to get a subsidy for these types of projects because we know we are taking risks. And that we would like to share that risk …we are not more pious than the pope, so subsidies are, now and then, the determining factor if a project is somewhat fragile" (Technical director company D)

Company D expressed their interest in developing such concepts in **collaboration with technology suppliers**:

"We have certain needs, but we are not machine builders. We probably do not have enough knowledge. And apparently the suppliers can also not do it by themselves; that's why we participate in these consortia with multiple parties" (Technical director company D)

Company D expressed less interest in **collaboration with energy advisors** on these topics due the **sector-specific knowledge** required to suggest process improvements:

"But in the paper process you need a certain amount knowledge so that you do not change something for a particular (energy) gain, that comes with a (energy) cost somewhere else that is twice as strong." (energy systems engineer company D)

The heat pump supplier became insolvent, and the project was on hold at the time of interviewing.

3.2 Supply chain interviews & workshops

The alignment of the supply chain for high-temperature industrial heat pumps is essential for effective rollout and market uptake of heat pumps. This section presents the results from interviews and workshops with companies involved in the development, installation, and maintenance of industrial heat pumps for an end user and the challenges they experienced. All of the participating companies had an operating presence in the Netherlands.

3.2.1 Interview results

Eight interviews were conducted with representatives (project/account/innovation managers, business developer, managing director) from companies at various positions in the supply chain (component suppliers, heat pump supplier, contractor, consultant, skid builder) (see annex A.1). The challenges for developing, implementing, and maintaining industrial heat pumps were analysed and categorised into two topics: challenges between companies involved in the supply chain, and challenges the supply chain experienced with end users.

Challenges *between companies* involved in the supply chain included a "lack of skills and resources" and a "lack of training", which were experienced by most interviewees (see Figure 3.2**). The full list of quotes is given in annex B.1.**

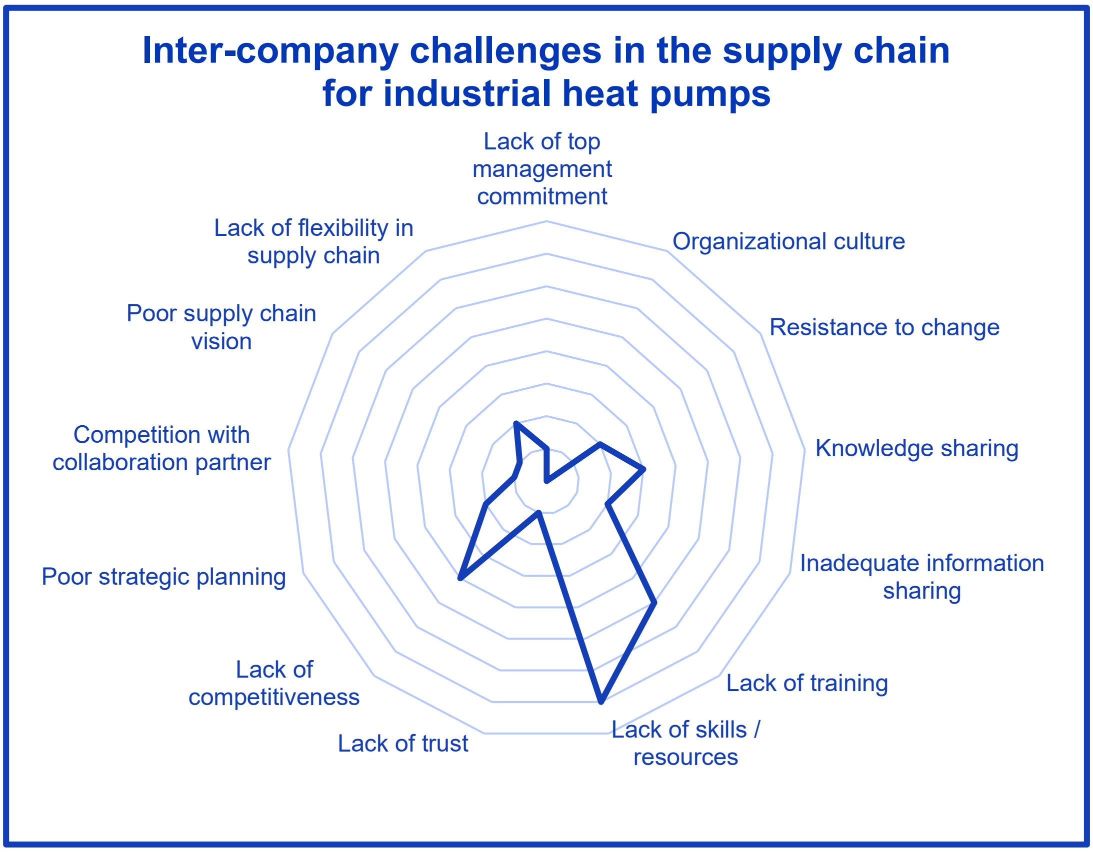

Figure 3.2: Collaboration challenges experienced by the supply chain in the development, implementation, and maintenance of industrial heat pumps. Results show the count (N =8) of the interviewees who experienced this challenge with other members of the supply chain.

Lack of skills and resources was mentioned in most of the interviews. These challenges related to a lack of skilled personnel, the ageing of technicians, a lack of process engineers, skilled installers, and the attractiveness of the field, e.g. willingness to do shift work or weekend work. As one interviewee stated, there is a "*lack of people who understand the challenge. There is an issue with installation*."

Lack of training was mentioned in more than half of the interviews with regard to challenges within the supply chain. This challenge relates to the aforementioned lack of 'skills and resources', but more specifically identifies the lack of available training in relation to engineers and industrial technicians who understand both heat pumps and the application sector. As a contractor stated "*They [installation and maintenance companies] need technicians. They need to train people in the new technology, because each project is a bit different*." Training additionally relates to refrigeration engineers to realign their knowledge with that of industrial heat pumps. As the expansion valve interviewee stated "*Yes, people who understand the system and for example how to balance the heat stream. We do have a lack of people ".*

Challenges experienced by actors in the supply chain *with end users* included "poor strategic planning", a "lack of trust", and "resistance to change" (see Figure 3.3**).**

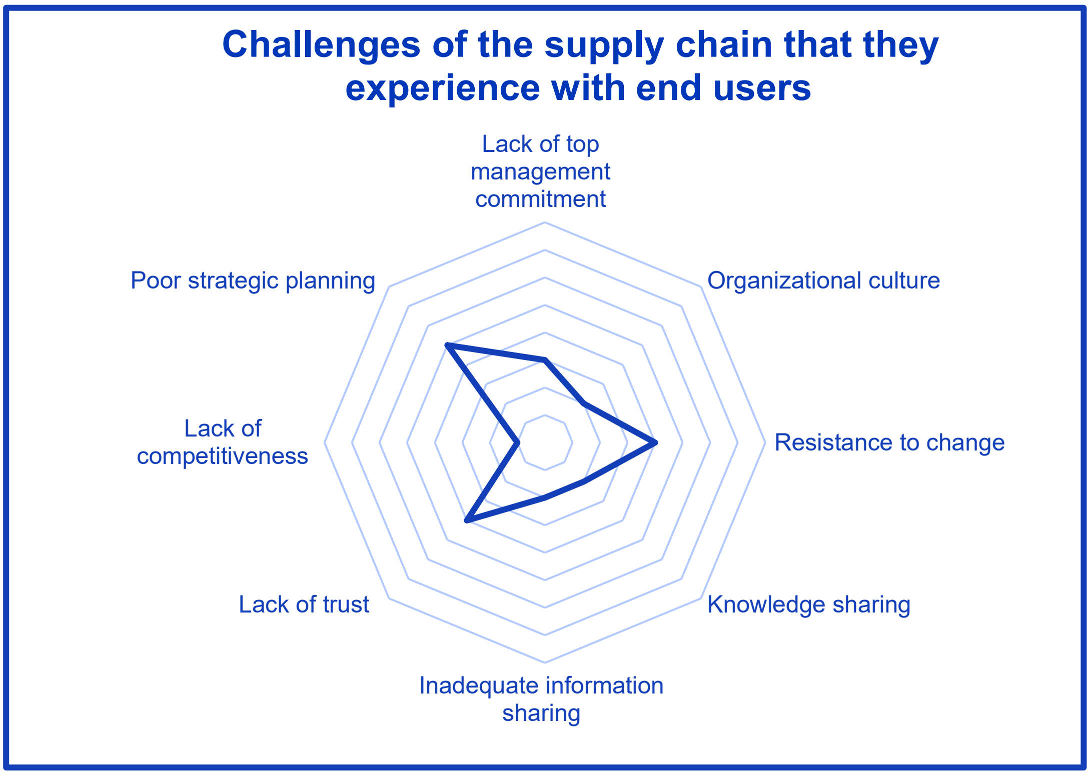

Figure 3.3: Collaboration challenges experienced by the supply chain in their interactions with end users in the development, installation and maintenance of an industrial heat pump. Results show the count (N =8) of the interviewees who experienced this challenge with end users. Note: the challenges that scored “0” were excluded from this spider plot. These excluded challenges are “lack of skills / resources”, “lack of training”, “knowledge sharing”, “lack of flexibility in the supply chain”, “competition with supply chain partner”, and ”poor supply chain vision”.

Poor strategic planning was mentioned by more than half of the interviewees concerning challenges they experienced with end users. A lack of long-term planning by the industry over grid connections can lead to project delays, due to issues of net congestion and long lead times for connection. As one contractor stated, “*Sometimes with [the] end user they realize too late* [i.e. due to changes in energy prices] *they want or need a heat pump*.” Supply chain companies further argued that, to inform better planning, end users must also have an accurate overview of their process, via an energy balance, before any decision on a heat pump can be made.

Lack of trust was mentioned by half of the interviewees concerning the end user. This concerns a general level of trust in the technology; it’s supposed merit on the end user side and ability of the supply chain to deliver it. For example, if a heat pump can generate the same quality of heat/steam as needed before; or, in the event that the core process temperature needs to drop to improve heat pump performance, that the drop will not affect product quality. The lack of demonstrator projects of high-temperature heat pumps contributes to this argument, as end users don’t have a working example they can look to for confirmation of the effectiveness of the technology and ability of the supply chain to deliver it (de Boer et al., 2020; Wesseling et al., 2022). As one interviewee stated *“end users want to see it working regarding technology reliability. On production level [we don’t] … experience hesitance to implement the heat pumps. It’s a challenge to install in brownfield but not a reason for operations to not do it*.”

In addition, trust also related to certain chemicals, primarily natural refrigerants, e.g. ammonia, carbon dioxide. “*There is a small challenge… maybe with ammonia, from end users, also towards natural refrigerants*. “For the supply chain, having a good, close, and trustful relationship with the end user was argued to be important for providing the conditions for pursing an industrial heat pump project.

Resistance to change was mentioned half of the times by the interviewees concerning the end user. This resistance concerned the perceived attitudes of the end users towards modifying and altering their core process by incorporating a heat pump – this was only referenced in relation to brownfield projects. Interviewees argued that end users are so familiar with steam as an energy source, they are sceptical and reluctant to move beyond it. As argued by a contractor, resistance to change was “*from end users. They are only used to using steam* “. Many solutions providers, particularly consultants stated they were extremely busy with requests and projects, allowing them to ‘pick and choose’. End users, according to them, who wait too long, are likely to be unable to find good, reliable partners.

3.2.2 Workshop results

Two workshops were organised with actors in the supply chain (see annex B.2 and B.3) to triangulate the interview results and elaborate upon them by exploring the strengths, weaknesses, opportunities, and threats (SWOT). These discussions focused almost exclusively on brownfield sites.

Perceived strengths and weaknesses of the supply chain
A summary of the self-described strengths and weaknesses is presented in Table 3.1. Supply chain actors indicated that promising strengths of the supply chain related to the fact that the supply chain is an existing one (using refrigeration technology suppliers). Consequently, the suppliers and the network is already formed and known (Strength 2 (S2)). In addition, workshop participants indicated the high level of knowledge within the supply chain. This was argued to be particularly strong among consultants who argued they facilitate between suppliers and end users (S3 & 5).

However, the weaknesses for the supply chain also related to a number of structural factors and aspects relating to the collaboration between supply chain actors. Structural challenges related to the already mentioned lack of labour or skills, particularly the availability of technicians and skilled personnel to meet expected future demand (Weakness 4 (W4)). This conclusion, taken together with the aforementioned strength of knowledge (S3), would indicate the technical knowledge is within the supply, but lack a suitable workforce to support implementation. Alternatively, the market position of industrial heat pumps was perceived as a more structural weakness, due to longer payback times which can be up to five years compared to alternative technologies (such as e-boilers) (W2) (Johnson Controls, 2021).

Issues relating to collaboration dynamics included the potential conflict of interest between partners, which can hamper cooperation (Weakness 3 (W3)); one example given was the risk of a ‘reverse takeover” if companies cooperated too closely. Finally, the challenge of decision making within the supply chain, e.g. coordinating and managing so many parties (W1) was frequently outlined. This weakness was given extra attention, as there was a level of disagreement between workshop participants over who should take this role between the contractor, technology provider, or the consultant / energy advisor. One conclusion from this discussion was the need for an ‘independent’ third actor to help mitigate frictions of this dynamic.

Table 3.1: Strengths and Weaknesses of a SWOT analysis of the supply chain to implement and maintain an industrial heat pump as outlined by companies in the supply chain

Strengths	Weaknesses
1. (S1) **Recover waste heat & reduce gas consumption**, two of the biggest benefits of heat pump use, for example, in the paper industry (which has a high energy consumption) 2. (S2) Uses **existing technology and existing collaboration**, e.g. the refrigeration supply chain. This will make the process of technology and process innovations smoother. 3. (S3) All **knowledge is available** (within this group). The workshop group contained extensive knowledge of end users and knowledge to design and implement industrial heat pumps. 4. (S4) Heat pumps have **a high efficiency** compared to e-boilers, leading to lower electricity use over time. This is helpful with the limited available grid capacity. 5. (S5) **Availability of consultants** who know the topic, technology, and field. They have a lot of expertise at hand. 6. (S6) **Waste heat can be buffered** meaning more (excess) energy can be stored (and used when energy prices are high). Heat pumps can be combined with energy storage, which can potentially contribute to grid flexibility.	1. (W1) In the process of developing and implementing a heat pump, it is unclear how and when **decisions** are made by whom within the supply chain. Better coordination and orchestration are needed. 2. (W2) A heat pump currently requires **higher investment costs, and therefore a longer payback time (compared to e-boilers)** than end users are used to with fossil-fuelled heat technologies. However, as mentioned, they have a higher efficiency performance in comparison to e-boilers. 3. (W3) **Conflicting interests** between parties in the supply chain. For example, companies competing for the same customers or market position can inhibit collaboration. 4. (W4) **Labour supply**: The availability of technicians and technical engineers to install and maintain heat pumps is insufficient to meet current/future demand. This relates to numbers but also to knowledge, e.g. of varying refrigerants such as propane, ammonia, or carbon dioxide. Currently, in the Dutch refrigeration market, there is a 'outflow' of workers. This poses a structural problem to the future of the industry.

Opportunities and threats as perceived by the supply chain
Actors involved in the supply chain saw many opportunities and a large market potential for industrial heat pumps (Primarily in brownfield projects), which can contribute to the decarbonization efforts of end users. These are presented in Table 3.2. Heat pumps were described as providing a "standard scalable solution" (Opportunity 2 (O2)). In addition, supply chain actors saw the merits of further and better collaboration, not only to "deal with the limits of human capital" (O4), but also to share more knowledge and expertise between parties (O6). Given that skills and human capital were frequently mentioned as structural issues, this proposed solution was received positively in the workshop.

Nevertheless, actors in the supply chain outlined various threats to the sector and to further market development. These threats related to various structural factors, such as electricity pricing (Threat 1 (T1)), net congestion (T2) and government rules and regulations (T3 &7). Threats that relate to the more direct area of control for the supply chain was the perception that end users did not trust the technology (T5), which was also outlined in the interviews. One area is for closer cooperation between process engineers and technology suppliers (T5).

Table 3.2: Opportunities and Threats of a SWOT analysis of the supply chain to implement and maintain and industrial heat pump as outlined by companies in the supply chain.

Opportunities	Threats
1. (O1) A heat pump is a **'worry-free solution'** **[**i.e., it can operate 24/7 at a high efficiency] and thereby providing a 'good night's sleep' for end users / customers. 2. (O2) There is the possibility within the supply chain to develop and a **provide standard scalable interface and solution.** However, this requires further and better collaboration. 3. (O3) **Further collaboration** within the supply chain has the potential to speed up the market development. This results in greater education of the whole supply chain and end users in heat pump technology. 4. (O4) There is opportunity within the supply chain to collaborate and develop a critical mass to **deal with the limits of human capital.** This will hopefully speed up the market growth. 5. (O5) There is an opportunity for the supply chain to **educate end users** in the technology and it's potential. There is also the potential to learn more about the internal workings of the supply chain. 6. (O6) The component suppliers can share **more knowledge and information on components,** e.g. heat exchangers and natural refrigerants (e.g. propane, isobutane, and isopentane) to both end users and other actors within the supply chain. It can also provide free engineering because of this knowledge. 7. (O7) End user adoption can make a **substantial difference for decarbonization,** for example by replacing gas as an energy source with electricity.	1. (T1) **Relative electricity price** in the future can make or break a heat pump business case, if the electricity to gas price ratio is high. 1) (T2) **Net congestion**: Can sufficient and consistent electricity be supplied to end users for connecting the heat pump? The communication between the end users and their planning with grid operators is essential, but also the type of contract and existing waiting list. 3. (T3) Government rules on refrigeration / refrigerants and if they can be used. 4. (T4) Currently, there is (almost) no **collaboration** between the heat pump developments and process engineers. 5. (T5) First of its kind syndrome on the end user side. End users are reluctant to invest in an alternative heat source, as they fear their **end-product** will be **affected** by the change in the production process. 6. (T6) Threat for the Dutch and/or European components and technology manufacturing from **cheap production overseas.** 7. (T7) **Legal aspects:** some end users want to innovate, but there are internal legal barriers. For example, the possibility of a ban on PFAS in manufactured products was perceived to be a challenge to providing solutions to end users.

4 Discussion

The non-technical barriers that hamper the adoption of industrial heat pumps manifest within different actors and contexts. Based on our results, we argue there are three key levels of analysis where these barriers are applicable. These three levels and their definitions are:

- **Ecosystem:** Barriers at this level do not originate from the heat pump supply chain but result from broader trends across industries, markets, and national energy-systems.
- **Supply chain:** Barriers at this level originate from the heat pump supply chain; all actors involved in the design, implementation, and maintenance of industrial heat pumps, excluding the end user (see Figure 3).
- **Project:** Barriers at this level originate from the interaction between end users, technology suppliers, and energy advisors of industrial heat pumps.

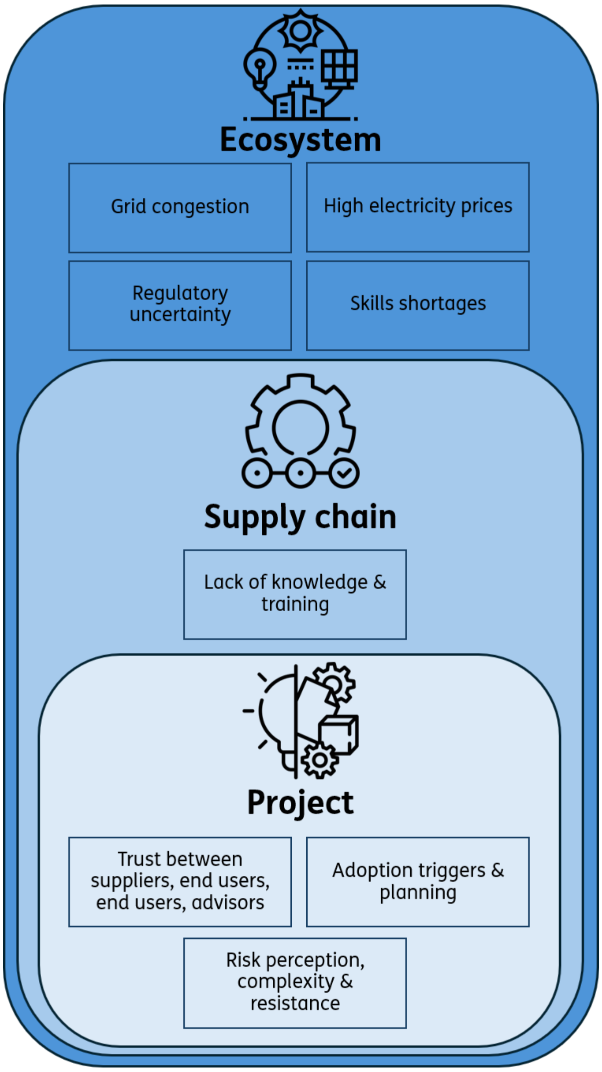

Figure 4.1: Identified barriers on three levels: ecosystem, supply chain and project.

4.1 Ecosystem barriers

1. **High industrial electricity prices have a profound effect on the business case for an industrial heat pump, which can severely hamper deployment**. Industrial energy consumption in the EU is mostly provided by electricity and natural gas. In 2024, the EU's industrial sector used 8 835 petajoules of energy, of which, 33,3% came from electricity and 31,9% from natural gas (Eurostat, 2026). For context, industrial energy prices are high in Europe compared to other countries (with the exception of the UK) (Trinomics B.V., 2022) causing strain on Europe's industrial sectors. Heat pumps become more attractive as investments when the electricity price is competitive against the price of alternative energy sources (e.g. natural gas) or when CO_2 emissions are sufficiently taxed. Here the electricity/gas price ratio becomes important indicator (see Figure 4.2), where a high ratio decreases the attractiveness to switch too an industrial heat pump(EHPA, 2025a). This barrier was mentioned by supply chain actors (Section 3.2) and is found to be a barrier to heat pump uptake across studies (Aydemir et al., 2026; EHPA, 2026b; Rosenow et al., 2025).

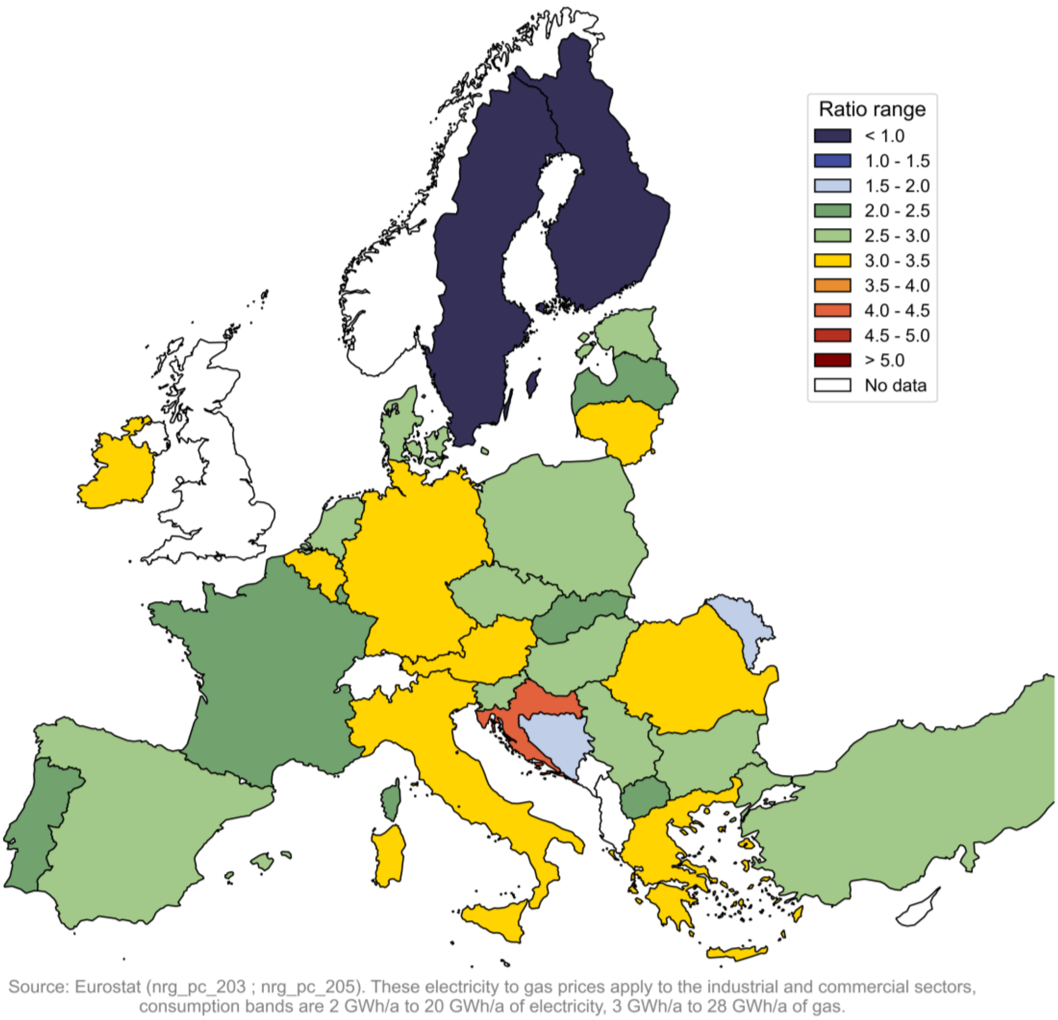

Figure 4.2: Electricity to gas price ration for industry – first half of 2024. Source EPHA using Eurostat data (EHPA, 2025a).

2. **Grid congestion, and associated long waiting times, prevent the connection of new assets, such as heat pumps, to the grid.** Figure 4.3 shows the Dutch grid connection capacity available for consumption (left) and feed-in (right) in October 2024. The lack of grid capacity slows project development down and inhibits planning and final investment decisions on the side of industrial end users. The limiting effect of grid congestion on heat pump adoption was mentioned by supply chain actors (Section 3.2) and is found to hamper adoption across studies (EHPA, 2026b; Rosenow et al., 2025).

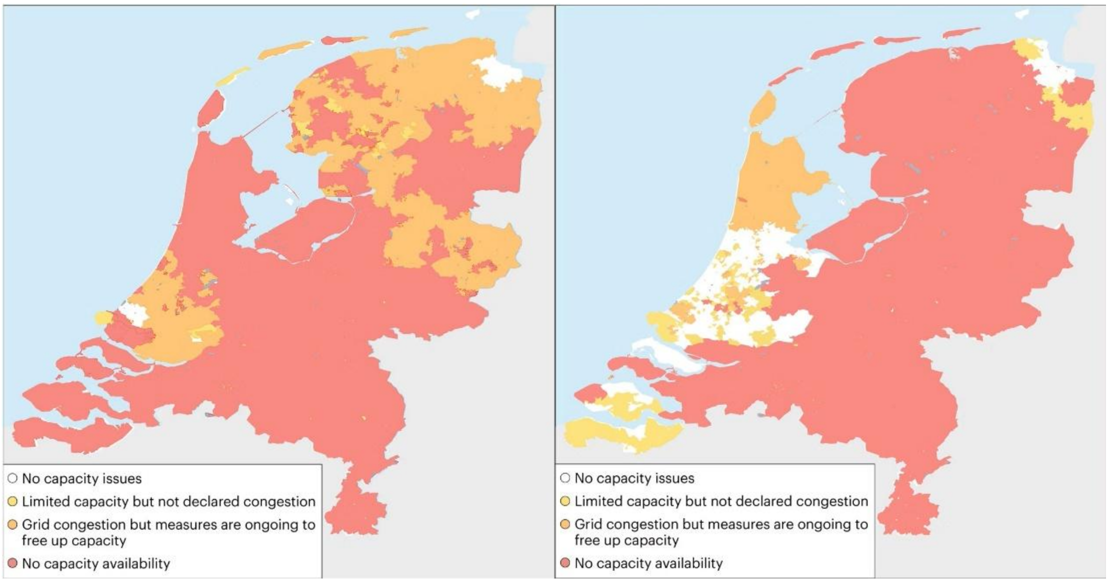

Figure 4.3: Map showing grid connection capacity available for consumption (left) and feed-in (right) in the Netherlands, October 2024 (IEA, 2025).

3. **Skills shortages across the sector are a structural barrier and are projected to get more severe.** Figure 4.4 shows the gap between the current and projected EU workforce (in 2032) for residential and industrial heat pumps. If the market projections for heat pumps materialize (McKinsey, 2024), major workforce shortages may arise for skilled technicians and engineers, as well as qualified employees who can handle different refrigerants, such as ammonia, carbon dioxide or propane (see section 3.2). These shortages present both an immediate shortage in competent personnel, and a longer-term human capital issue (EHPA, 2023b). The (projected) skills shortages in the supply chain are widely recognized as a barrier to industrial electrification in the literature (EHPA, 2026b; Rosenow et al., 2025).

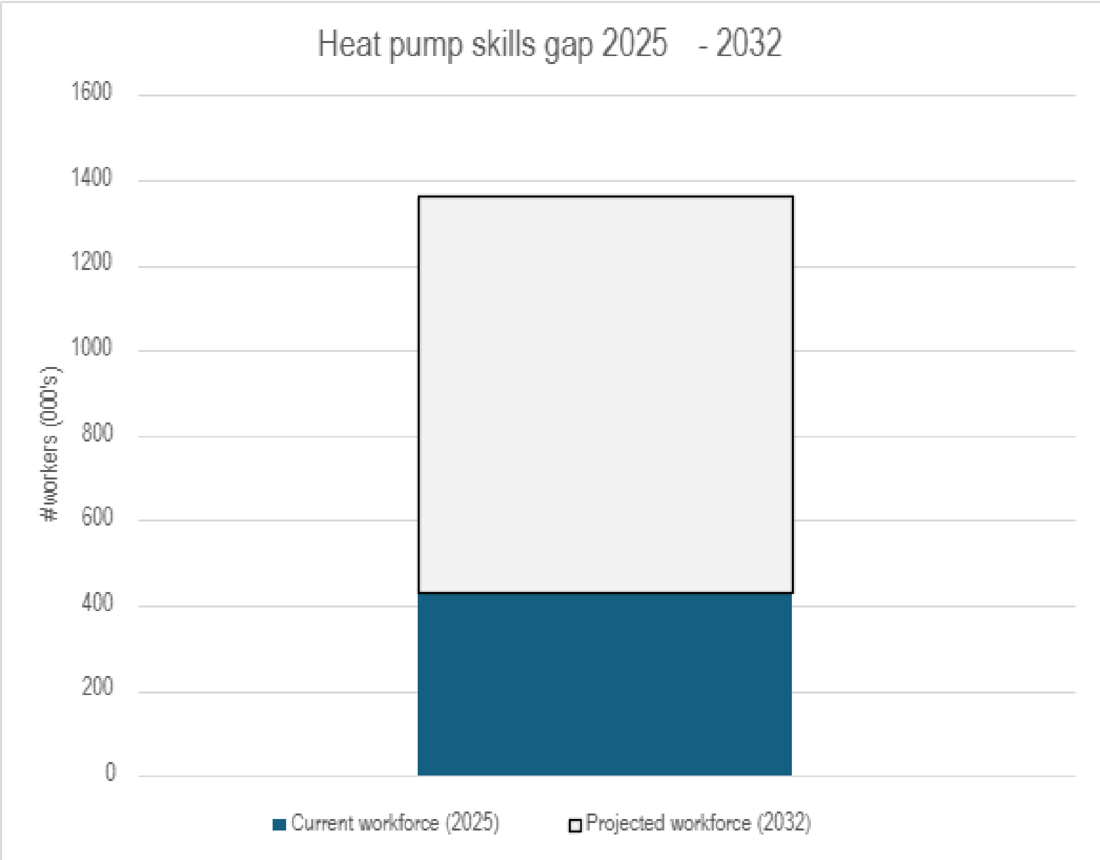

Figure 4.4: Current and future heat pump skills needed in Europe. (Source: EHPA, 2026. Figure own creation TNO)

4. **Regulatory uncertainty can prevent supply chain actors from pursuing heat pump development projects.** Two examples mentioned during this research pertain to the permitting requirements for specific refrigerants, such as ammonia or CO_2, and the ban on PFAS in manufactured products (see Section 3.2.2 and Case C in Section 3.1). Companies may reduce regulatory uncertainty by proactively acting upon potential regulatory requirements; for example, by investing in an industrial heat pump with alternative refrigerants or components (see Case C in Section 3.1). Other studies have also identified unclear regulation as a barrier to adoption (Aydemir et al., 2026; EHPA, 2026b).

4.2 Supply chain barriers

1. **A lack of training in combining heat pump and production process knowledge hampers the integration of heat pumps into existing processes.** Supply chain actors perceived a major barrier to be the lack of training in heat pump technology for engineers and industrial technicians, as well as specific training for refrigeration engineers to realign their knowledge with industrial heat pumps (e.g. on natural refrigerants) (see Section 3.2). The lack of combined knowledge of both electric heating technology and production processes is recognised in the literature as a major barrier to industrial electrification (EHPA, 2026b; Rosenow et al., 2025).

Some authors (McKinsey, 2024) suggest that engineering, procurement and construction companies (EPCs) may provide such combined expertise, but throughout the case studies this expertise was often perceived to be lacking by the end users. Whether such perceptions are driven by a lack of trust, a preference for independently developing expertise or by experiences with EPCs that lacked the right expertise is not fully clear.

4.3 Project barriers

Challenges experienced in the collaboration between technology suppliers, end users and energy advisors were mentioned from both the supply chain side (see section 3.2), as well as the end users' side (see section 3.1). The challenges can be summarized into three main areas:

1. **Unpredictable adoption triggers at the end users' side poorly suit the need for long term planning at the suppliers' side:** Supply chain actors struggle with what they perceive as poor strategic planning from the potential end users of heat pumps. These actors mentioned that end users do not, for example, account for the time needed to apply for and obtain a grid connection for industrial projects; obtaining such a connection is difficult due to grid congestion issues. Yet, from the end users' side, the adoption process for a heat pump may be triggered by (unexpected) changes in external conditions that (suddenly) create a window of opportunity for investment. The adoption triggers in cases B, C, D are all caused by such changes in external conditions (see Section 3.1). Although other end users, such as case A, may start the adoption process as part of the ongoing maintenance or improvement of production processes, internal company dynamics (e.g. gaining management approval for investment) may still cause the timing of the various stages of adoption to be highly unpredictable.

   Even in more predictable situations, suppliers may still be involved too late in the development of the heat pump business case, causing end users to struggle with the trade-offs between various alternatives for generating heat (e.g. heat pumps, e-boilers or hybrid boilers) (Copernicus Institute of Sustainable Development & ISPT, 2019). Such late involvement may also be driven by trust issues or organisational culture, rather than issues with regards to planning (see 'trust' barrier). Furthermore, a lack of strategic planning and the late involvement of supplier may be related to the priority and level of interest within the specific company in energy efficiency; the higher the priority, the higher the likelihood for better planning regarding such measures (Kooger, 2018).

2. **Risk perceptions, mistrust, technological complexity, and resistance to change jointly prevent investment in heat pumps by end users.** Developing novel heat pump applications may be seen as inherently complex by both end users and technology suppliers (see case C in Section 3.1). End users may hesitate to invest in such novel applications because they see them as too complex, risky, or unproven. From the suppliers' side, such perceptions may be perceived as a resistance to change by the end user and a hesitance to move beyond what they are familiar with. Supply chain actors also mentioned that many end users need to see the envisioned heat pump applications working in practice. The novelty and lack of pilots demonstrating the reliability of (high temperature) heat pumps may indeed be the primary driver of the expressed risk perceptions (Rosenow et al., 2025), preventing end users from confirming the effectiveness of the technology and of the ability of the

supply chain to deliver it (Copernicus Institute of Sustainable Development & ISPT, 2019; de Boer et al., 2020; EHPA, 2026b).

The importance of piloting and collaboration as a means of managing the (inherent) risks involved in developing novel heat pump applications was also mentioned by some end users (see case D in Section 3.1). The importance of developing pilots is echoed by the supply chain actors in the interviews (see Section 3.2). Reframing heat pump investments as a pilot – with the added goal of learning and knowledge development – may also improve the odds of attaining management approval for investment.

These heat pump perceptions are likely highly intertwined with one another and may all be at play simultaneously. Our interviews show such perceptions and attitudes may also be strongly embedded in the organisational culture, where risk aversity or a preference for proven technology steers decision making (see case B in section 3.1). For some companies, such perceptions may originate from the importance of minimizing risks to production continuity and food safety (Aydemir et al., 2026). Such perceptions may be specific to the sectors we examined in this project, primarily the food and beverage sector.

3. **Distrust between end users, technology suppliers and energy advisors may hamper heat pump business case development and implementation.** Both supply chain actors and several end users mentioned trust in others as a key issue fostering or hampering heat pump adoption. On the one hand, a lack of trust may lead to frustrated communication efforts between suppliers and end users and can increase perceptions of risk or technology un-provenness (see case B). On the other hand, trust in others may help to move projects forward that would have been seen as too complex or risky without such trust. Trust may also attenuate the unpredictability of adoption triggers where longstanding collaborations may be used to kickstart projects that may have to be implemented suddenly (e.g. due to changes in external conditions (see case C)).

   With regard to the energy advisor and end user relationship, some of the end users expressed scepticism toward the added value of bringing in outside knowledge to develop heat pump business cases. In their perspective, the added value was limited due to the difficulties of understanding the (sometimes organically or haphazardly expanded) production processes and sometimes embedded in a general need for independence from outsiders (see case B)).

5 Recommendations

A policy framework should be developed that tackles barriers at each of the three levels identified in Chapter 4 (ecosystem, supply chain, project). Resolving barriers at the ecosystem level is needed to improve the business case for (specific types of) heat pumps and mobilize the resources (financial, human capital, network) needed for their adoption. Strong (financial) incentives are also needed to create a sense of urgency at the end user side and to foster commitment from their top management for such investments.

Such a policy framework has already been developed for the Netherlands through the action agenda electrification (In Dutch: “Actieagenda Elektrificatie Industrie”) (Ministerie van Klimaat en Groene Groei, 2025). The action agenda specifies actions for improving policy consistency, financial incentives, innovation and knowledge sharing and the flexible operation of assets. At the European level, various policies and programs are in place to tackle the ecosystem barriers. As these policies and programs have been discussed extensively elsewhere (EHPA, 2026b; Rosenow et al., 2025), we focus on recommendations for tackling the supply chain and project level barriers in this report.

Resolving barriers at the supply chain and project levels is needed to foster collaboration between the various actors involved in heat pump development, implementation, and maintenance. Improvements in (at least) three areas are needed to foster such collaboration.

1. **Develop a program for systemically de-risking industrial heat pumps.** Risk perceptions may be driven by the lack of industrial heat pump showcases. A coordinated program for systematically de-risking investment in these heat pumps through showcasing or experience sharing may attenuate risk perceptions. Such a coordinated program has not yet been developed, despite the funding of several research projects focused on showcases (e.g. MOOI Kickstart and Horizon Europe SPIRIT) (Aydemir et al., 2026; Rosenow et al., 2025).

   Such a program may have a twofold focus on (1) developing heat pump showcases and (2) creating awareness of ongoing showcases. Showcases may be developed more easily in low-risk cases within production locations open to innovation and risk (e.g. case A) where the heat pump can serve as a testbed for future, gradual rollout of similar heat pumps. Awareness creation programs may further boost exposure of existing showcases by offering site visits, matchmaking events, or exchange programs between existing and potential heat pump end users. Financial support for such initiatives, as well centralising communication through a central service desk (e.g. an enterprise agency), may be needed to ensure their creation and success (EHPA, 2026b).

   The program should also foster cross-domain knowledge exchange to equip engineers with the skills to apply heat pump concepts to various use cases, sectors, and companies. For example, SMEs involved in heat pump development could be supported by funding for attending conferences focused on such knowledge exchange.

   A key condition for the effectiveness of showcases is the willingness of the showcases’ host to show their plant to interested parties. Companies hosting showcases may be hesitant to do so in fear of disclosing confidential information about their production process, comprising their competitive position in turn. Although such fears may be unfounded, they may hamper the end users' openness to knowledge sharing. Given the importance of knowledge sharing to reducing perceived investment risks, funding agencies should consider granting subsidies only when showcase activities take place. They should also investigate how end users' fears around showcasing can be alleviated, by setting conditions on attendance, setting, or scope of the showcase.

Such showcasing may be dually advantageous for first mover countries. First, greater deployment of industrial heat pumps offers steps towards industrial decarbonization. Second, showcasing and heat pump deployment generate economic opportunities for the supply chain, in particular EPCs (Engineering, Procurement and Construction companies), energy advisors and technology providers who gain project experience that can be applied elsewhere, aiding them in capturing future international market share.

2. **Build enduring partnerships between end users, suppliers, and energy advisors.** The Kickstart case studies showed the importance of trust between end users, technology suppliers, and energy advisors in the heat pump adoption process. Such trust may be fostered by building enduring partnerships between them and by co-creating new (collaborative) business models, such as off-the-shelf heat solutions or rental models (including maintenance and support) (McKinsey, 2024). Off-the-shelf solutions may standardise the range of products on offer, leading to a simpler, more accessible purchasing process for buyers of heat pumps. Heat-as-a-service models free end-users from having to operate the equipment themselves (e.g. steam use in breweries[7]), while rental models may lower CAPEX requirements for investment. Yet, such models may be a poor fit for end users focused on independence as a core value (e.g. case B).

   Enduring partnerships may be kickstarted by developing Collaborative Business Models (CBMs) that focus on shared value creation. An example of a CBM is a building team (in Dutch: 'bouwteam') where contractors, end users and technology suppliers jointly integrate the heat pump into the production process. A building team focuses on collaborative design instead of a strict division of responsibilities across the various steps in heat pump integration.

   Workshops have already been developed to guide partners through the stages of developing such a business model. Yet their uptake is currently limited. Trusted partners, such as Energy Service Companies (ESCo's), could stimulate the uptake of these approaches by creating awareness among their clients about their potential benefits. Network organisations (e.g. the European Heat Pump Association; EHPA), industry organisations (e.g. FNLI, VNCI or MKB Nederland in the Netherlands) and enterprise agencies (e.g. RVO in the Netherlands) can offer training modules in these approaches, as they are already commonly the first point of contact for suppliers and end users for advice on regulations and subsidies.

   A condition for the uptake of CBMs is upfront organisational support. Engineers, business developers, and plant managers need to invest time and effort in developing the CBM, possibly before its advantages to the company's goals or KPIs have become clear. Without organisational support, they are unlikely to be able to participate in trainings or workshops or to successfully champion the CBM's development within their organisation.

[7] HEINEKEN pioneers one of the largest heat battery systems in Portugal in partnership with EDP and Rondo Energy

3. **Develop training programs to reduce the skills gap.** People with the skills to integrate heat pumps into existing processes, combining process expertise and electrification technology expertise, are scarce. Existing information channels are insufficient for building such skills, necessitating a more coordinated approach through targeting specific regions or clusters and taking advantages of potential synergies of between industrial facilities (Rosenow et al., 2025). Such a coordinated program may include (1) EU-wide certifications and training programmes for engineers and technicians in industrial sectors (EHPA, 2025c), (2) resources to retrain contractors and installers and (3) investments in vocational and university programs for sustainable heating technologies, as well as on-the-job-training (EHPA, 2026b). Such initiatives may foster the attractiveness of the field and narrow the skills gap for heat pump installation and maintenance.

In addition to these policy recommendations, further research is needed in several areas to further elucidate the key barriers to heat pump adoption:

1. **The scope of the problem should be identified in more detail to sharpen its policy relevance.** Recent studies have identified the potential of heat pumps for businesses or business parks in the Netherlands (TNO, 2024). Other studies show that the potential is not being met through a lag in the adoption of heat pumps. Yet it is currently unclear to what degree such adoption is hampered by the non-technical barriers found in this project. In other words, what savings in, for example, natural gas use could be achieved by tackling the barriers discussed above.

   To this end, quantitative data on subsidy applications (e.g. the investment subsidy renewable energy (ISDE) in the Netherlands), their use by various industries and adoption rate among these industries may shed light on which industries are commonly affected by the non-technical barriers identified above. If possible, comparisons between countries in heat pump uptake could aid in drawing conclusions about the mismatch between policy regimes for heat pumps and their actual uptake.

2. **The barriers found throughout current studies need to be validated with quantitative data and/or in-depth case studies.** The case studies and interviews conducted throughout the Kickstart project have identified perceived barriers for the adoption of industrial heat pumps, focused on companies with an operating presence in the Netherlands, primarily in the food and paper sectors. Yet, to which degree these barriers are shared across companies, sectors and countries is still unclear. A recent study conducted a survey among European end users and suppliers of heat pumps, but the response rate was too low to draw any generalizable conclusions on adoption barriers (EHPA, 2026b). Further studies should aim to provide more substantive quantitative data on adoption barriers, although they are likely to run into similar issues with low response rates to surveys.

   Furthermore, it is unclear which of the identified barriers are critical to successful heat pump adoption. Most studies identify barriers to adoption by interviewing potential key actors before adoption has taken place or once the adoption process has finished. Further studies should focus on providing longitudinal data on adoption processes by tracking barriers throughout the adoption process, by using journalling, observations, or recurring interviews.

3. **The effectiveness of collaborative solutions should be tested through experiments.** Collaborative solutions, such as Collaborative Business Modelling, have the potential to tackle planning issues, build trust, and reduce risk perceptions. Yet it is currently unclear whether collaborative solutions are more effective than non-collaborative solutions at fostering heat pump adoption. Further studies should experiment with collaborative solutions and evaluate their effectiveness, as well as the effectiveness of trainings in teaching collaborative skills.

4. **Recent geopolitical developments may necessitate more attention towards risks for the security of supply for heat pump components.** While supply constraints of specific materials or components were not mentioned during the workshops, supply chains are reckoning with rapid geopolitical changes since then[8]. For example, export controls of permanent magnets or Rare Earth Elements from China have caused delays across aerospace, automotive and defence domains (RSM, 2024). Consequently, at the European level, the policy focus is shifting to not only meeting decarbonization goals but also maintaining industrial competitiveness and reshoring production. The recent critical raw materials act (2024) is illustrative of this focus shift. The act outlines that no more than 65% of any critical material (from separate mining or processing stages) can come from a single country of origin, while pushing to increasing materials processing capacity (European Commission, n.d.). Thus, understanding the potential supply risks, of components or materials to the European heat pump industrial ecosystem could provide a fruitful area of research, building towards decarbonization and continuation of the existing European industrial heat pump ecosystem. A starting point for research is to map suppliers of critical components and their sub-components (e.g. compressors, heat exchangers, condensers, expansion valves) to understand supply vulnerabilities.

[8] Note: the supply chain workshops and research were undertaken in 2023, since then the geopolitical situation has changed significantly.

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References

Aydemir, A., Alsheimer, S., Kantel, A., & Hirzel, S. (2026). *Exploring Barriers to Heat Pump Adoption in Industry: Insights from a Survey*. In Review. https://doi.org/10.21203/rs.3.rs-9179690/v1

Carlsson, B., & Stankiewicz, R. (1991). On the nature, function and composition of technological systems. *Journal of Evolutionary Economics*, *1*, 93–118.

Copernicus Institute of Sustainable Development & ISPT. (2019). *Industriële warmtepompen in Nederland. Een innovatiesysteemanalyse.* https://energy-innovation.nl/documents/1036/Industri%C3%ABle_warmtepompen_in_Nederland_Een_innovatiesysteemanalyse.pdf?_gl=1*jncoiu*_gcl_au*NDc4NTYzMDA2LjE3NzY4NjgyMzA.*_ga*Njc4NzIwNjAzLjE3NzY4NjgyMzA.*_ga_XX5Z11WKJT*czE3NzY4NjgyMjkkbzEkZzAkdDE3NzY4NjgyMzMkajU2JGwwJGgxNTE0MzE2MzQ0

de Boer, R., Andrew Marina, Benjamin Zühlsdorf, Cordin Arpagaus, Michael Bantle, Veronika Wilk, Brian Elmegaard, José Corberán, & Jessica Benson. (2020). *Strengthening Industrial Heat Pump Innovation. Decarbonizing Industrial Heat*. https://repository.tno.nl/SingleDoc?docId=51462

DNE Research. (2026). *Nationaal warmtepomp trendrapport.* https://www.dutchnewenergy.nl/nationaal-warmtepomp-trendrapport/

EHPA. (2023a). *Heat Pumps in Europe. Key Facts & Figures*. https://www.ehpa.org/wp-content/uploads/2023/06/Heat-Pump-Key-Facts-May-2023_compressed.pdf

EHPA. (2023b). *Wanted: Half a million heat pump workers*. https://ehpa.org/news-and-resources/news/wanted-half-a-million-heat-pump-installers/#:~:text=26%20Jan%202023,how%20should%20it%20be%20done?

EHPA. (2024). *European Heat Pump Market and Statistics Report 2024*. https://www.ehpa.org/wp-content/uploads/2024/08/Executive-summary_EHPA-heat-pump-market-and-statistic-report-2024-2.pdf

EHPA. (2025a). *Electricity versus gas prices: What's the picture for industry?* https://ehpa.org/news-and-resources/news/electricity-versus-gas-prices-whats-the-picture-for-industry/

EHPA. (2025b). *European heat pump market report*. https://www.ehpa.org/wp-content/uploads/2025/07/EHPA-Market-Report-2025-executive-summary.pdf

EHPA. (2025c). *Industrial heat pumps to decarbonise Europe's industry*. https://www.ehpa.org/wp-content/uploads/2025/03/20250304-EHPA-Industrial-Heat-pumps-position-paper81.pdf

EHPA. (2026a). *Pump it up. Why heat pump sales rose in 2025—A country by country breakdown*. https://ehpa.org/wp-content/uploads/2026/03/20260325_Pump-it-up-why-heat-pump-sales-rose-in-2025_EHPA.pdf

EHPA. (2026b). *SPIRIT deliverable 5.2: Policy, regulatory and non- technical barriers.* https://spirit-heat.eu/wp-content/uploads/2026/01/D5.2-Policy-regulatory-and-non-technical-barriers.pdf

European Commission. (n.d.). *Critical Raw Materials Act—Internal Market, Industry, Entrepreneurship and SMEs*. Retrieved April 23, 2026, from https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en

European Commission. (2026). *Proposal for a Regulation on establishing a framework of measures for accelerating industrial capacity and decarbonisation in strategic sectors (Industrial Accelerator Act).* (COM(2026)100). https://single-market-economy.ec.europa.eu/document/download/9bc8eb85-4d43-4025-be7b-c86b9f3648ec_en?filename=Proposal%20establishing%20measures%20for%20industrial%20capacity%20and%20decarbonisation%20in%20strategic%20sectors%20.pdf

Eurostat. (2026). *Energy use in the industry sector continues to decline*. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20260529-1

IEA. (2025). *Grid congestion is posing challenges for energy security and transitions.* https://www.iea.org/commentaries/grid-congestion-is-posing-challenges-for-energy-security-and-transitions

IEA Heat Pump Centre. (2025). *Industrial High-temperature Heat Pumps. Task 1—Technologies* (HPT-PR68-2). https://doi.org/10.23697/9b7b-sz34

International Energy Agency. (2022). *The Future of Heat Pumps*. OECD. https://doi.org/10.1787/2bd71107-en

Johnson Controls. (2021). *Heat pump or boiler: What's the business case?* https://www.johnsoncontrols.co.uk/-/media/project/jci-global/johnson-controls/uki-region/united-kingdom/insights/2021/whitepaper/files/wp-jci-iref-district-energy-white-paper-062021.pdf

Kooger, R. (2018). *INDUCE D2.2: Best practice guideline*. https://www.induce2020.eu/wp-content/uploads/sites/12/2019/11/INDUCE-D2.2-Best-practice-guideline-.pdf

Marina, A., Spoelstra, S., Zondag, H. A., & Wemmers, A. K. (2021). An estimation of the European industrial heat pump market potential. *Renewable and Sustainable Energy Reviews*, *139*, 110545. https://doi.org/10.1016/j.rser.2020.110545

McKinsey. (2024). *Industrial heat pumps: Five considerations for future growth.* https://www.mckinsey.com/industries/industrials/our-insights/industrial-heat-pumps-five-considerations-for-future-growth

Ministerie van Klimaat en Groene Groei. (2025). *Actieagenda Elektrificatie Industrie*. https://open.overheid.nl/documenten/68a7254c-e99b-436b-8d62-e8d1bc3c3044/file

PBL & TNO. (2023). *Energy efficiency options in the Dutch manufacturing industry. Manufacturing Industry Decarbonisation Data Exchange Network (MIDDEN).* https://www.pbl.nl/uploads/default/downloads/pbl-2023-energy-efficiency-options-in-the-dutch-manufacturing-industry-5256.pdf

Rosenow, J., Arpagaus, C., Lechtenböhmer, S., Oxenaar, S., & Pusceddu, E. (2025). The heat is on: Policy solutions for industrial electrification. *Energy Research & Social Science*, *127*, 104227. https://doi.org/10.1016/j.erss.2025.104227

RSM. (2024). *New Chinese Export Control Regulation: Impact on Global Business Using Chinese-Origin Goods | Netherlands*. https://www.rsm.global/netherlands/en/insights/new-chinese-export-control-regulation-impact-global-business-using-chinese-origin-goods

RVO. (2026). *SCE/SDE projecten in beheer* [Dataset]. https://ez.maps.arcgis.com/apps/dashboards/04077558b37243dbbfda0d9ec694ab12

TNO. (2024). *Potentie energiebesparing bedrijventerreinen* (TNO 2024 R10511). https://publications.tno.nl/publication/34642259/XJK6ys/TNO-2024-R10511.pdf

Trinomics B.V. (2022). *Study on energy prices and costs: Evaluating impacts on households and industry - 2023 edition.* https://doi.org/10.2833/782494

Wesseling, J., Kieft, A., Fuenfschilling, L., & Hekkert, M. (2022). How socio-technical regimes affect low-carbon innovation: Global pressures inhibiting industrial heat pumps in the Netherlands. *Energy Research & Social Science*, *89*, 102674. https://doi.org/10.1016/j.erss.2022.102674

Appendix A
Research method

A.1 Introductory interviews

Eight interviews with the Kickstart consortium were conducted to understand the industrial landscape, challenges, and barriers for the industry. In Table A.1, the list of interviewees is described.

Table A.1: List of interviewees for the introductory interviews

#	Position in supply chain	Position in Company
1	Compressor supplier 1	Project manager
2	Compressor supplier 2 & technology supplier	Account manager
3	Consultant	Project manager
4	Skid builder	Managing Director
5	Technology supplier	Project manager
6	Contractor	Project manager
7	Heat exchanger supplier	Business developer
8	Expansion valve supplier	Innovation manager

A.1.1 Interview protocol

Introduction (10min)

Objective of the Kickstart project:
To accelerate the implementation of industrial heat pumps by

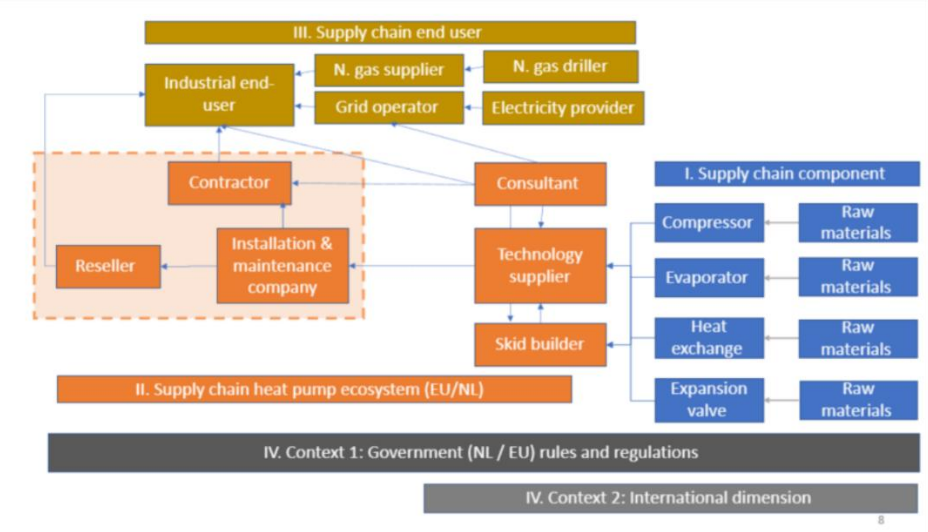
1. Developing technological solutions that are a commercially viable alternative to fossil fuel fired heating systems for industrial heat demand < 200°C, both for brown field and green field applications.
2. Identifying the main non-technical barriers that hamper market implementation and how to reduce them.

Purpose of this interviewing round:
We would like to discuss your experience working in [company name]. The aim of this is to gather an overview of the current activities and challenges in delivering an industrial heat pump and to create a better understanding of the roles, challenges, and drivers for developing the supply chain for industrial heat pumps.

Based on this/these interviews, we plan to organize several workshops, where the insights of this interview will be used. The results from this workshop and these interviews will be shared in a confidential report with workshop participants and with an anonymized research report.

Introduction interviewee (10 min)

- Person & role / Function
- Organisation
  - Can you tell me about your organisation and what it does?
  - What is the ambition of your organisation?
- Position in Supply Chain [Show Supply Chain-map]
  - What part of the supply chain are you active in and what are the activities you do within it?
  - For the delivery of a heat pump, what stakeholder in the supply chain are you most dependent on? And for what: *Equipment, Knowledge, Resources, Financial, Other?*



Heat pump adoption challenges (15min)

We are interested to understand what the challenges to market creation are for actors in the supply chain.

- What is needed to grow the market?
- What policy or regulatory challenges do you experience?
- What manufacturing challenges do you see? [or have you perceived?]
- What knowledge challenges do you experience?
- Do you see challenges in securing the components for industrial heat pumps?
- If tomorrow the demand for IHP would double, what would the biggest challenge be for the supply chain?
- What other challenges do you perceive?
- Which of these challenges is the biggest? To whom in the supply chain does this apply? [bottleneck]

Supply chain collaboration challenges (15min)

Now, I would like to talk about your experience of collaboration in the supply chain for the development, implementation, and maintenance of an industrial heat pump.

- Which of the following challenges do you recognise?
  - Can you elaborate? Maybe give an example.
  - Does the challenge occur mostly in collaboration with the end user or the companies you work with in the supply chain?
- What are the top three challenges from your organisation?
- Is this different for a green or brownfield applications?

Challenge Name	Present? (Elaboration & with end user or within supply chain)
Knowledge sharing	
Poor strategic planning	
Competition with collaboration partner	
Poor supply chain vision	
Lack of trust	
Inadequate information sharing	
Lack of top management commitment	
Lack of training	
Organizational culture	
Lack of skills / resources	
Lack of competitiveness	
Resistance to change	
Lack of flexibility in supply chain	
Others	

A.2 Case studies of heat pump adoption

The four cases in the project were selected to represent a combination of greenfield and brownfield locations, as well adoption and non-adoption of heat pumps. For each of the case studies, semi-structured interviews were conducted with multiple representatives at the end user side, as well as the technology supplier and energy advisor (if any) involved in heat pump adoption. In some of the cases, additional information (e.g. website or site visit reports) was used to provide context and details.

The interviews consisted of a series of case-specific questions, as well as general questions on the presence of common energy efficiency barriers at the end user side. In some interviews, the interviewee was asked to reflect on key statements from other interviews. The primary focus of the analysis reported here was the case description and timeline. Discussions on common energy efficiency barriers were included when they were explicitly linked to the heat pump adoption process.

The interview transcripts were sent to the interviewees for approval and (if needed) clarification. All of the interviewees signed an informed consent form before the interview, detailing the conditions for participation in the interview and the use of their data for research purposes.

A.2.1 Interview protocol

Introduction, background and interview aims
The KickStart project has the objective to accelerate the implementation of industrial heat pumps by:

- Developing technological solutions that are a commercially viable alternative to fossil fuel fired heating systems for industrial heat demand < 200°C, both for brownfield and greenfield applications.
- Identifying the main non-technical barriers that hamper market implementation and how to reduce them.

Despite their potential to reduce the CO_2 emissions in various industrial sectors, notably paper, chemicals and the food industry, industrial heat pumps are not widely adopted yet by industrial parties (the end users). Specifically, implementation of HP in the temperature range of 120-200°C. In this study, we seek to get a better understanding of these challenges, by studying a couple of cases of adoption or non-adoption in detail. Outcomes of the study will be used to develop recommendations for lowering barriers to adoption of HP technology as well as other process technologies with high CO_2 emission reduction potential.

- To this end, we conduct interviews and workshops with all key players in the supply chain, including end users like yourself.
- The aim of this interview is to understand the challenges for industrial heat pump adoption from the perspective of the end users.

Purpose of this interviewing round

- Learn about your experiences with adoption (or non-adoption) of an industrial heat pump in one specific case study.
- Learn about your experiences with adoption (or non-adoption) of decarbonization technology in production processes, more generally.
- Learn about your needs to accelerate adoption of these technologies.
- To this end, we encourage you to talk from personal experience.

Practical agreements
With your permission, sound recordings will be made of these interviews. In the informed consent form, you can indicate to (not) give your permission for this. We will send you the minutes of this interview afterwards with the request to check if we have correctly noted your responses. As announced in the participant letter, the data will be pseudonymized. The final report of this study will be made public. In this report, the case study will not be linked to your specific company, unless your company prefers otherwise. Rather, we will talk about "Company A from the food/chemical sector". When we use quotes from your interview, we will only mention your function, no personal information.

Introduction organization and interviewee

Name/role:
Organization:
Date:

Main responsibility, day-to-day activities:
Key activities, Value proposition, Customer segments:
What is the ambition for your organisation in the coming 3 years?

Discussing case study
- Client/Location:
- Greenfield or Brownfield?
- Project status:
- Name supplier:
- Aim of the project? E.g, improve product, improve process, new product/process?:
- Type of heat pump:
- Efficiency coefficient and temperature range:
- Type of compressor: Piston/Screw/new type:

Can you give us a brief description (max. 5 minutes) of the project, from start to present?

[Note to interviewer: Ensure that the above questions are answered but use the questions below only as prompts where needed, either to ensure the conversation is about the process (rather than technological details) or to focus on aspects that seem particularly interesting. No need to ask all questions, since it will take too much time.]

Project description, timeline. *When started? Current status? Decision moments: Company need, rough specification, selecting suppliers, further specification, offers, choices, realisation, commissioning, maintenance.*

People involved. *What was your role/responsibility in this project? Who else had a relevant role/responsibility in this project? What did the team look like? Who has the ultimate responsibility for this project? Who approves decisions?*

Prior experience HP (end user only). *Was this your company's first experience with Heat Pumps?*

Supplier selection (end user only). *Why this supplier? Were other suppliers considered? What made this supplier win the bidding process? First time working with this supplier, or existing relationship?*

Project criteria. *What were the most important criteria for this project? Were sustainability criteria among them? Was decarbonization also a driver? And energy efficiency? Have you had any discussion about these aspects? Which arguments were raised?*

Result. *What were the results of this project? What was its contribution to decarbonisation/energy efficiency?*

Evaluation. *Has your company conducted a project evaluation? Was the result in line with expectations? In hindsight, could anything have been done differently to achieve an even better outcome in terms of sustainability? What should have happened to create that outcome?*

Personal experience. *What have you personally learned from this project? What would you do different next time?*

Representativeness. *In your experience, was this project different from others, or similar? In what respect different, in what respect similar?*

Drivers and barriers for investing in EE measures
In previous research, some drivers and barriers for investing in EE measures have been identified. We would like to discuss with you to what extent these are at play within your company, and specifically within the Heat Pump case we have just discussed.

I am going to show you a list of problems and causes, I will first take you through it, and they we will discuss to which problems and causes you want to respond. There is no need to have an answer to everything.

Problems:
1. Energy Efficiency is a low priority during investment decision-making by top management.
2. Energy efficiency is not a priority for location/plant managers. There is high resistance to change production processes.
3. Operational process change is experienced as highly complex and a lot of (extra) work.
4. Lack of skills/resources within the company to take into account energy efficiency in projects at the end user.
5. Lack of trust in energy advisors.
6. Lack of energy advisors.

Questions for each of the problems:
- Do you recognize this problem at all? Do you think it is as described here?
- Do you recognize this problem in your company (end users)/ in your experience with end users (suppliers)?
- Do you agree with the assumed cause of the problem?
- How can we see that in the specific case (or not)?
- If not, do you have another example?
- Do you agree with the suggested solution?
- What could help you solve this problem/adopt the solution?

A.3 Supply chain workshops

To understand the barriers the supply chain experienced in developing, installing, and maintaining industrial heat pumps, two workshops were organised.

A.3.1 Workshop 1: Barriers and vision forming

The first workshop aimed to:
1. Create a shared understanding of the key challenges to market creation and collaboration (greenfield, i.e. new factory/processes and brownfield, integration into the existing process)
2. Create a shared awareness of the leverage points and areas of influence, i.e. the places where internal and external intervention can positively change the supply chain, to address these key challenges.

Outline of the workshop:
1. Welcome and introduction
   a. Supply chain collaboration challenges (TNO)
      Presentation by TNO about the outcomes of the introductory interviews
   b. Case study (by Energy Advisor)
      Presentation by an energy advisor about a project in which non-technical issues occurred.
   c. Discussion
2. Break-out sessions to discuss the two main challenges
   Method: Group discussion on what are the main variables/sub-challenges regarding skills and resources and knowledge sharing?
   a. Skills and resources: The skills, knowledge and experience possessed by an individual and organisation, and the ability to deploy them.

    b. Knowledge sharing: Knowledge of technical specifications & process, e.g. willingness and ability to share.
3. Reflection on group discussions & wrap-up

Table A.2: List of present companies at workshop one

#	Company type
1	Compressor supplier
2	Heat exchanger component supplier
3	Component supplier
4	Technology supplier
5	Consultant
6	Technology and compressor supplier
7	Technology supplier
8	Installation and maintenance company
9	Heat exchanger component supplier
10	Contractor
11	Compressor supplier
12	Compressor supplier

A.3.2 Workshop 2: Business model development

The second workshop aimed to:

1. All supply chain actors are connected and mobilized and can understand how to utilize the available knowledge and skills of others
2. The supply chain actors are aware of their individual roles and the roles of others to create a collective value proposition (for an end user)

Outline of the workshop:

1. Welcome and introduction
    a. Collective Business Modelling (TNO)
    Presentation by TNO about the collective business models
2. Designing a collective business model
    a. SWOT analysis
    Interactive assignment to list the strengths, weaknesses, opportunities, and threats of the supply chain for industrial heat pumps.
    b. Business Model Radar
    Interactive assignment to design a collective business model which describes (1) the collective value, which is created by the collaboration, (2) the role that each party fulfils in realising the collective value, (3) resources, capabilities and activities deployed, and (4) the costs and benefits
3. Cross presentation & evaluation.

Table A.3: List of present companies at workshop two

#	Company type
1	Skid builder
2	Consultant
3	Compressor supplier
4	Heat exchanger component supplier
5	Heat exchanger component supplier
6	Consultant
7	Compressor supplier
8	Technology provider
9	Consultant
10	Compressor and technology provider
11	Heat changer component supplier
12	Heat exchanger component supplier
13	Compressor and technology supplier
14	Heat exchanger component supplier
15	Installation and maintenance
16	Installation and maintenance
17	Wire supplier
18	Compressor supplier
19	Technology supplier

Appendix B
Detailed description of the research output

B.1 Introductory interviews: Supply chain challenges with quotes

Challenge	Which member of the supply chain experiences this?	Who did this apply to most?	Examples (and with who)
Knowledge sharing	Skid builder, consultant, Contractor, Heat exchanger, Compressor supplier 1	Supply chain	**Supply chain:** Heat exchanger "Contractors. Not always aware of the technical limitations. Because they are new to this market as well. They have a lack of experience and people with a lack of experience." **Skid builder** "Yes, from the consultants. Should think wider than the problem. Too familiar with hot, not between hot and cold. Should think more holistic, not just write down what the customer wants. Should be aware between the difference of gas/heat pump solutions. So, knowledge sharing between hot & cold. " **End user:** Technology supplier "There is not enough knowledge on utilities from end user side. "

Challenge	Which member of the supply chain experiences this?	Who did this apply to most?	Examples (and with who)
Poor strategic planning	Technology supplier, Skid building, Contractor, Compressor supplier 1 & 2, Heat exchanger, Expansion valve supplier	End user	**Supply chain:** Expansion valve “Production capacity probably” **End user:** Compressor 2 “the end users are always too late with their planning”. **Contractor** “Sometimes with end user: they realize too late they want / need a heat pump.
Competition with supply chain partner	Compressor 1	Supply chain	**Supply chain:** Technology supplier “There is no competition. There is too much to do and everyone has their own specialization. Find solutions together for the client. There is not enough knowledge so therefore collaboration is more interesting instead of competing.”

Challenge	Which member of the supply chain experiences this?	Who did this apply to most?	Examples (and with who)
Poor supply chain vision	Compressor 1	Supply chain	**Supply chain:** Compressor 2 “every partner always knows better than the other one, so there can be a lack of trust in each other's knowledge. There are still rec builders, big parties worldwide, that claim that after 8-10 years you need a new rec, and that is nonsense. We need to develop trust that we can help each other and that we can build an installation that lasts from 30-40 yrs. We all want to do something for the environment, but we also still want to earn money. That is the economy we have built. But we need more collaboration with each other, we need to have more trust in each other to go to a certain environment and earn money altogether:” **End user:** Skid builder “Sometimes it goes slow. I see a vision with most producers. The market demand is higher than they can provide. There is a gap between speed of producers and the demand from end users. “
Lack of trust	Consultant. Contractor, Compressor 1, Compressor 2, Expansion valve	End user	**Supply chain:** Compressor 1 “every partner always knows better than the other one, so there can be a lack of trust in each other's knowledge. There are still rec builders, big parties worldwide, that claim that after 8-10 years you need a new rec, and that is nonsense. We need to develop trust that we can help each other and that we can build an installation that lasts from 30-40 yrs. We all want to do something for the environment, but we also still want to earn money. That is the economy we have built. But we need more collaboration with each other, we need to have more trust in each other to go to a certain environment and earn money altogether.” **End user:** Compressor 2 “end users want to see it working regarding technology reliability. On production level [we don’t] … experience hesitance to implement the heat pumps. It’s a challenge to install in brownfield but not a reason for operations to not do it.” Expansion valve “There is a small challenge. No maybe with ammonia, from end users, also towards natural refrigerants. “
Inadequate info sharing	Technology supplier, Consultant, Compressor 1, Expansion valve	Both equally	**Supply chain:** Compressor 2 “information sharing between contractors and installers. is also important and it is done improperly nowadays. If you get better feedback from installations, you can provide better solutions to the market. Contractors need to be open about that and share the data. We need information from end user and contractor. “ **End user:** Technology supplier “Info from end users. Knowledge of energy balance and process. “

Challenge	Which member of the supply chain experiences this?	Who did this apply to most?	Examples (and with who)
Lack of top management commitment	Contractor, Consultant, Compressor 1, Compressor 2	End user	**Supply chain:** Compressor 2 “Clearly, they [different supply chain partners] have a different view, they have to earn money.” **End user:** Contractor “Sometimes they feel they need more demonstrators.” Technology supplier “Always. Easier with family-owned businesses, not share holder organisations. They need to speak to the right person, e.g. an energy manager.”
Lack of training	Technology supplier, Skid builder, Contractor, Heat exchanger, expansion valve	Supply chain	**Supply chain:** Expansion valve “Yes, people who understand the system and for example how to balance the heat stream. We do have a lack of people “ Contractor “They [installation and maintenance] need technicians. They need to train people in the new technology, because each project is a bit different.”
Organizational culture	Technology supplier, Consultant	End user	**End user:** Technology supplier “Knowledge of processes of the end users.”
Lack of skills / resources	Technology supplier, Skid builder, Consultant, Contractor, Compressor 2, heat exchanger, expansion valve	Supply chain	**Supply chain:** Expansion valve “Lack of people who understand the challenge. [is an] issue with installation.” Heat pump supplier “There is too much demand at the moment and not enough knowledge.”
Lack of competitiveness	Technology supplier, Skid builder, Compressor 1, Heat exchanger, consultant	Supply chain	**Supply chain** Skid builder “Need more companies involved. Not enough delivering HP. Needs people and experience.” Expansion valve “No I don’t see a challenge when it comes down to components. But when the market explodes then the flees come to the butter; we fear that unskilled manufactures will come. “ **End user** Consultant “That’s true but they (end users) have to deal with it. It’s a sellers' market. There is too much work.

Challenge	Which member of the supply chain experiences this?	Who did this apply to most?	Examples (and with who)
Resistance to change	Technology supplier, Skid builder, Consultant, Contractor, Compressor 1, Compressor 2	End user	**Supply chain** Skid builder “For them, they need a different way of thinking. Refrigeration (cold) hesitant to engage with the hot because it requires a mind shift change “ **End users** Contractor “From end users. Only used to using steam. “
Flexibility in the supply chain	Consultant, Compressor 1, Compressor 2	Supply chain	**Supply chain** Technology supplier “Issue for lead times”

B.2 Supply Chain Workshop 1: Challenges

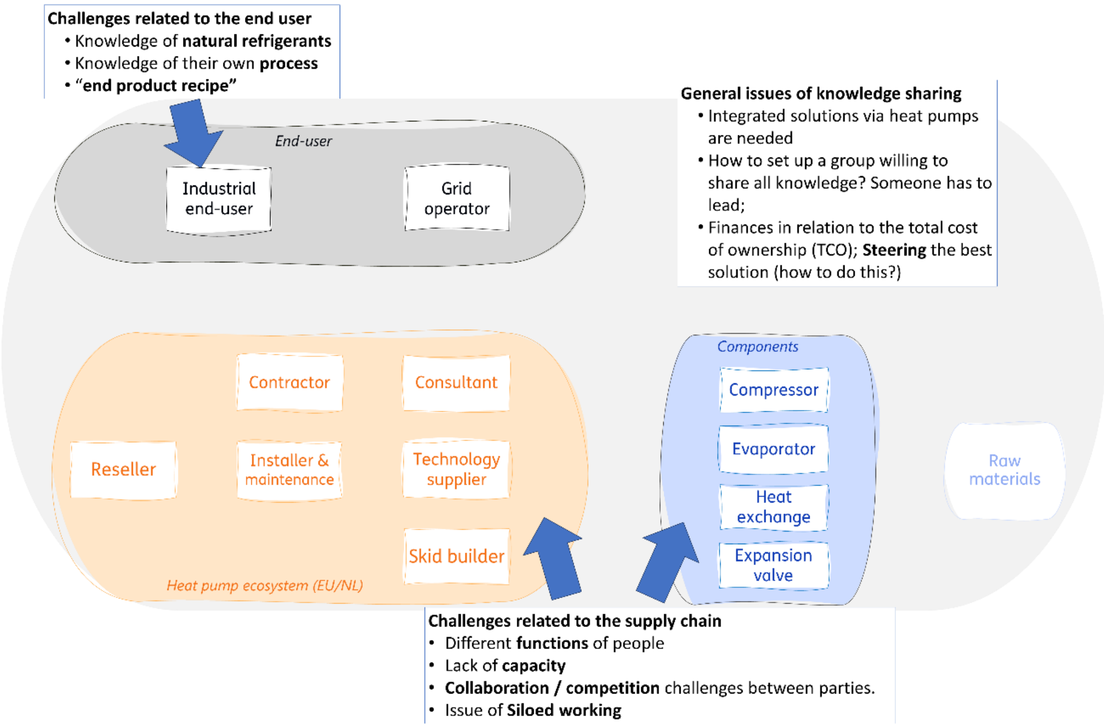


Figure 5.1: Outcomes of discussion on 'Knowledge Sharing'.

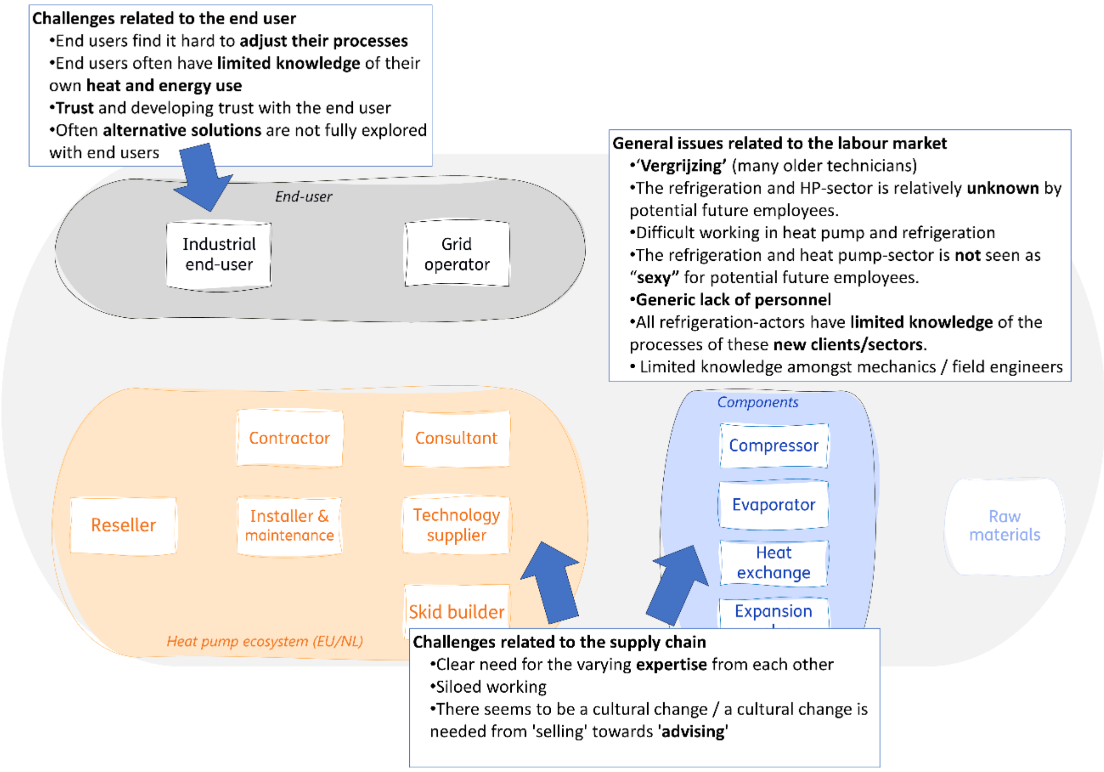


Figure 5.2: Outcomes of discussion on 'Skills and resources'.

B.3 Supply Chain Workshop 2: Collective Business Model Radars

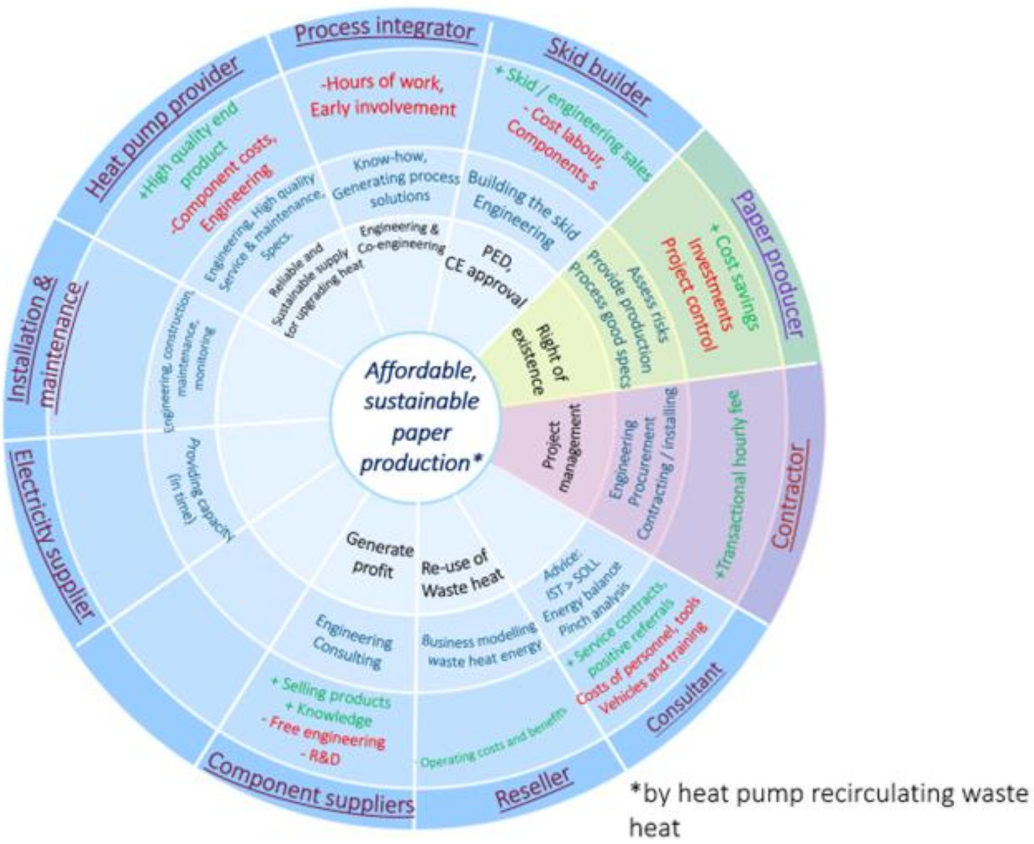


Figure 5.3: Group 1 collaborative business model radar.

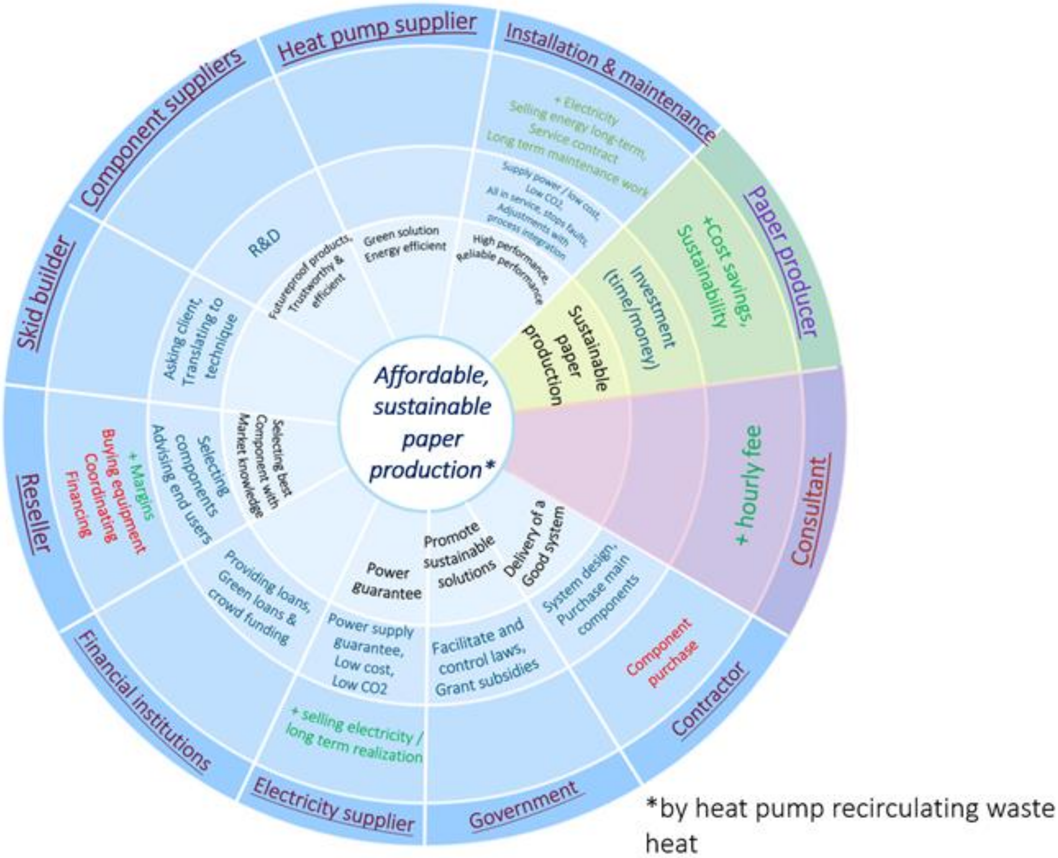


Figure 5.4: Group 2 collaborative business model radar.

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