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OBSERVATORY

# Heat Pumps in the European Union

## *STATUS REPORT ON TECHNOLOGY DEVELOPMENT, TRENDS, VALUE CHAINS & MARKETS*

2024

EUR 40066

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**Contact information**
Name: Agne Toleikyte
Email: JRC-PTT-HEATCOOL@ec.europa.eu

**EU Science Hub**
https://joint-research-centre.ec.europa.eu

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## Contents

## Abstract

This report provides an update on the state of the art of heat pump technology, including its application in buildings, industry, and district heating and cooling. It presents installed capacity, sales and projections, and an analysis of research and development trends. It also discusses EU competitiveness in the global value chain and identifies potential supply risks.

As of 2023, there were more than 21.5 million heat pumps installed in the EU. Between 2013 and 2022, heat pump sales experienced continuous growth, reaching a peak in 2022 when they increased by 44% compared to the previous year. However, 2023 saw a slowdown, with a drop of 7% compared to the record year. The main reasons for the slowdown were the decrease in gas prices, the overall economic context (construction activity, interest rates, inflation), perceived unstable financial schemes, and political uncertainty. Other barriers might hamper the rate of growth in the medium term, such as installer shortages, volatile metal prices and disruptions to the supply of components such as semiconductors or permanent magnets.

The European heat pump industry has committed to significant investments, with over EUR 7 billion earmarked for capacity expansion between 2020 and 2030. However, the 2023 sales decline has put pressure on companies to recover their investments. At the same time, the industry's trade deficit declined by one-third in 2023. The European heat pump industry is poised to capitalise on the anticipated growth in demand, leveraging its established presence, expertise, and innovation to capture a significant market share in the long term.

## Foreword on the Clean Energy Technology Observatory

The European Commission set up the Clean Energy Technology Observatory (CETO) in 2022 to help address the complex and multi-faceted character of the transition to a climate-neutral society in Europe. The EU's ambitious energy and climate policies create a necessity to tackle the related challenges in a comprehensive manner, recognising the important role for advanced technologies and innovation in the process.

CETO is a joint initiative of the European Commission Joint Research Centre (JRC), which runs the Observatory, and Directorate-Generals Research and Innovation (RTD) and Energy (ENER) on the policy side. Its overall objectives are to:

- monitor the EU research and innovation activities on clean energy technologies needed for the delivery of the European Green Deal;
- assess the competitiveness of the EU clean energy sector and its positioning in the global energy market;
- build on existing Commission studies, relevant information and knowledge in Commission services and agencies, and the Low Carbon Energy Observatory (2015-2020);
- communicate findings by publishing reports on the Strategic Energy Technology Plan (SET-Plan) SETIS online platform.[1]

CETO provides a repository of techno- and socio-economic data on the most relevant technologies and their integration in the energy system. It targets in particular the status and outlook for innovative solutions as well as the sustainable market uptake of both mature and inventive technologies. The project supports EU competitiveness in clean energy technologies, and EU research and innovation policy.[2]

The observatory produces a series of annual reports addressing the following topics:

- Clean energy technology status, value chains and markets: covering advanced biofuels, batteries, bioenergy, carbon capture utilisation and storage, concentrated solar power and heat, geothermal heat and power, heat pumps, hydropower and pumped hydropower storage, novel electricity and heat storage technologies, ocean energy, photovoltaics, renewable fuels of non-biological origin, renewable hydrogen, solar fuels and wind;
- Clean energy technology system integration: building-related technologies, digital infrastructure for smart energy systems, industrial and district heat and cooling management, standalone systems, transmission and distribution technologies, smart cities and innovative energy carriers and supply for transport;
- Foresight analysis for future clean energy technologies using weak signal analysis;
- Clean energy outlooks: analysis and critical review;
- System modelling for clean energy technology scenarios;
- Overall strategic analysis of clean energy technology sector.

More details are available on the CETO web pages.[3]

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[1] https://setis.ec.europa.eu/what-set-plan_en.

[2] https://energy.ec.europa.eu/topics/research-and-technology/clean-energy-competitiveness_en.

[3] https://setis.ec.europa.eu/publications/clean-energy-technology-observatory-ceto_en.

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Authors: Agne Toleikyte, Eric Lecomte, Jonathan Volt, Lorcan Lyons, Juan Carlos Roca Reina, Aliki Georgakaki, Simon Letout, Aikaterini Mountraki, Moritz Wegener, & Andreas Schmitz

## Executive summary

Heat pumps are crucial for a successful clean energy transition and achieving the EU's carbon neutrality goal by 2050. Specifically, they are expected to play a significant role in the buildings sector, where the use of ambient heat is projected to triple by 2030, and in industry, where heat pumps capable of reaching temperatures up to 100°C could cover up to 11% of Europe's process heat demand.

Heat pumps are versatile systems that provide heating, cooling, and hot water in buildings. As the building sector continues to transition towards carbon neutrality, the integration of heat pumps into existing buildings through energy renovation has emerged as a critical element for achieving this goal. In industries, heat pumps supply heat for specific processes, while in district heating and cooling (DHC) networks, they can facilitate the integration of waste and renewable heat sources. In terms of technology readiness, heat pumps for building applications are considered mature, with a Technology Readiness Level (TRL) of 9. Industrial heat pump technologies have also made significant progress, with those suitable for temperatures below 140°C reaching a TRL of 8 or higher. However, the TRL for industrial applications between 140°C and 200°C varies, ranging from 4 to 9, depending on the specific temperature and capacity requirements.

Despite significant growth, heat pumps still lag behind fossil fuel-based boilers as the dominant individual heating technology in European buildings. As of 2023, there were over 21.5 million heat pumps installed in the EU, but this represents only a fraction of the total market. In DHC networks, large heat pumps account for just 1% of total capacity. However, after a remarkable 44% surge in 2022, the heat pump market experienced a notable slowdown in 2023, with sales declining by 7%. This decline can be attributed to a combination of factors, including a shift in energy prices, a challenging economic environment, and increasing uncertainty around future policy support.

From an affordability perspective, heat pumps often offer a more cost-effective solution than gas boilers in residential buildings, thanks to their high efficiency and resulting energy savings. However, the upfront cost of heat pumps remains a significant hurdle for many consumers, presenting a major barrier to adoption. The financial viability of heat pumps is heavily influenced by their operating costs. However, in several EU countries, gas remains significantly cheaper than electricity, largely due to tax policies that favour gas. This disparity creates a challenge for heat pumps, particularly in the industry sector where high-temperature applications are often more cost-effective with fossil fuel-based alternatives. Nevertheless, ongoing research, development, and innovation (RD&I), combined with strong political and financial commitments to decarbonise industrial processes, are expected to drive down costs and improve the competitiveness of heat pumps over time.

When it comes to RD&I, the Strategic Energy Technology Plan (SET Plan) identified the main areas for heat pumps, which include reducing costs for small and large heat pumps, improving heat pump design for wider compatibility, and developing prefabricated, modular heat pumps for large-scale applications. For high-temperature heat pumps, the focus is on reaching TRL 7 by 2025 for those producing temperatures of 200-250°C, and TRL 6 for those producing temperatures above 250°C. Public investments in heat pump RD&I in the EU decreased in 2023, although not all countries disclosed their data. Innovation, venture capital and corporate investments at all stages grew in the EU by almost 50% in 2023, with the EU leading globally, followed by the United States.

The data suggests that between 60% and 73% of heat pumps installed in Europe are also produced in Europe. There are approximately 255 heat pump facilities across 21 Member States, with the largest numbers in Italy, Germany, Poland, France and the Netherlands. However, the EU manufacturers are mainly assemblers, with many components imported from outside the EU.

The EU plays a pioneering role in the global hydronic and industrial heat pump markets, with a comprehensive network of key suppliers across the region covering the whole value chain. The EU is also home to approximately 36 manufacturers of commercial large-scale heat pumps, thus being a leader also in this field.

Value chain trends in production value and employment are positive. In 2023, the value of EU heat pump production increased by 30% compared to the previous year, reaching more than EUR 5 billion. Taken as a three-year average, Germany and Sweden were the top EU producers. France was the largest EU producer in 2023 (EUR 1.3 billion). In terms of employment, the heat pump industry is the largest renewable energy sector, employing around 416 200 people (direct and indirect jobs) in 2022.

The main value chain vulnerabilities are centred on skills and materials. The shortage of skilled workers is currently a bottleneck in both domestic and industrial applications. Especially for industrial heat pumps, the design often needs to be customised to the specific criteria of the end user. While the training for heat pump installation is relatively quick, there is strong competition for workers across clean energy technologies. Copper, aluminium and nickel are essential, as they are also used for many other clean energy technology value chains. Furthermore, heat pumps are vulnerable to disruption to the supply of components such as semiconductors and permanent magnets.

Between 2013 and 2020, the EU trade balance of heat pumps was in surplus, meaning that the EU exported more heat pumps than it imported. In 2020 however, the EU trade balance turned to a deficit for the first time, as a result of rising extra-EU imports, mainly from China. The extra-EU imports grew from EUR 0.5 billion in 2020 to EUR 1.4 billion in 2022. However, in 2023, the EU deficit was reduced by one-third. The EU has a strong presence in world trade as EU exports accounted for 26% of world exports during 2021-2023. In that period, China was the biggest exporter worldwide, followed by Germany, Sweden and France. The largest non-EU importers from EU producers are Switzerland, followed by the UK and Norway.

The continued growth of the heat pump market will necessitate a significant scaling up of EU heat pump manufacturing, as well as the domestic production of key components. EU suppliers have and are further ramping up production to maintain or grow their share of this market, which is expected to continue to grow. Announced investments in new and extended factories, as well as the repurposing of existing production lines, total about EUR 7 billion between 2020 and 2030. Industry stakeholders want to see long-term market predictability, based on a stable policy framework, which they see as key to safeguard and support these investments. Table 1 presents a SWOT analysis of heat pump competitiveness from an EU perspective.

**Table 1**: SWOT analysis of the competitiveness of EU heat pump manufacturing

| **Strengths** | **Weaknesses** |
|---|---|
| - High market share of EU manufacturers (assemblers).<br>- EU is a leader in the manufacturing of hydronic heat pumps and large heat pumps for various applications.<br>- No specific supply risks, a high degree of component commonality with other products.<br>- Proven technology.<br>- Strong investment pipeline. | - Production of some key components, compressors and refrigerants is dominated by a small number of suppliers outside the EU. |
| **Opportunities** | **Threats** |
| - EU can maintain its global leadership as producer of industrial heat pumps through standardisation, and wider application range for higher temperatures.<br>- The EU's move towards natural refrigerants opens the opportunity for its industries to lead in environmentally sustainable heat pump technologies.<br>- The EU's skilled manufacturers, with a robust investment pipeline, are well-positioned to improve competitiveness in other growing heat pump-sectors like air-air heat pumps.<br>- The entry of non-EU heat pump manufacturers may pose a competitive threat, yet could also introduce capital investment, innovation, and economies of scale through acquisitions or establishing subsidiaries. | - The drop in sales in 2023 has left many companies struggling to recoup their capacity investments.<br>- While the training for heat pump installation is relatively quick, there is strong competition for installers and energy experts.<br>- An increasing share of extra-EU imports is a threat to EU manufacturing. Imports from China have been rising for the past three years but from a low base and in the context of very rapid deployment overall. EU manufacturing capacity is adjusting, and extra-EU manufacturers may create subsidiaries in the EU, if they have not already, threatening current leaders. |

*Source: (JRC, 2024)*

# 1 Introduction

## 1.1 Scope and context

This report presents an overview of the current state of heat pumps in the European Union (EU). The report offers an analysis of the installed capacity and sales of heat pumps, tracking the progression of EU-funded research, development, and innovation (RD&I) in accordance with Strategic Energy Technology Plan (SET Plan) goals. Additionally, it evaluates the EU's competitiveness in the heat pump market, identifying potential bottlenecks and supply risks as the industry strives to meet the objectives of the European Green Deal.

Chapter 2 examines the current status and anticipated evolution of key technological indicators for heat pumps. It provides an overview of the technology readiness level (TRL) for various heat pump technologies and their applications (Section 2.1), discusses key metrics on installed capacity, sales, heat production, and develops modelling projections and deployment requirements (Section 2.2). The chapter also presents current and future cost trends for heat pumps, including estimates of Levelised Cost of Energy (LCoE), capital expenditures, and operational costs (Section 2.3). It outlines competitiveness indicators such as public and private RD&I funding, patenting trends, and scientific publications (Sections 2.4 to 2.7), and analyses the impact and trends of EU-supported RD&I activities (Section 2.8).

Chapter 3 presents an overview of the heat pump value chain, encompassing metrics like turnover, Gross Value Added (GVA), employment, and production. It also explores environmental and socioeconomic sustainability factors, assesses the presence of EU companies in the heat pump market, and identifies supply chain bottlenecks within the EU.

Chapter 4 concludes with an assessment of the EU's global standing and competitiveness. It evaluates the EU's market shares and scrutinises the trade balance with key competitors. Furthermore, the chapter explores supply risks and critical dependencies within the supply chain, examining the array of raw and processed materials utilised in heat pump production.

## 1.2 Methodology and data sources

The report has been written following the methodology of the Clean Energy Technology Observatory (CETO), which addresses three principal aspects:

a) Technology maturity status, development and trends;

b) Value chain analysis;

c) Global markets and EU positioning.

The Annex provides a summary of the indicators for each aspect, together with the main data sources.

# 2 Technology state of the art and expected development

### What are the main types of heat pumps?

Heat pump systems can be classified by their heat source (air, ground, or water) and by their method of distributing heating or cooling—either through air (via fan coils or air ducts) or water (channelled to radiators or in radiant heating and cooling systems). In Europe, the three most common types of heat pumps are air-to-water, air-to-air, and ground-to-water. Among these, electrically driven compression heat pumps are by far the most popular and efficient in terms of sales. Although compression heat pumps dominate the market, other options are available, such as gas-driven heat pumps and hybrid systems that integrate multiple technologies.

A compression heat pump is generally comprised of a) an outdoor unit that extracts heat from the air in the case of an air-source heat pump or a heat collector for ground- or water-source heat pumps; b) a heat pump unit containing two heat exchangers (evaporator and condenser), a compressor, an expansion valve and a controller; and c) a heat distribution (and in some cases storage) system.

An exhaust air heat pump is an air-source heat pump that, in addition to some outside air, recovers heat (at around 22°C) from a ventilation system. Exhaust air heat pumps typically integrate with ducting as part of a ventilation system, and they can also supply heat to water-based heating systems such as radiators or underfloor heating. These heat pumps are especially effective in buildings with low energy consumption due to their ability to recycle energy from exhaust air.

A hybrid system typically consists of a heat pump paired with an auxiliary heating technology, such as a gas boiler or an electric radiator, to provide supplemental heat when necessary. Additionally, solar thermal panels or photovoltaic-thermal (PV-T) collectors, which generate both electricity and heat, can be integrated into the system. Dual-source heat pumps that combine air- and ground-source ambient heat are also sometimes referred to as hybrid heat pumps; such systems are designed to optimise efficiency or reduce heat exchanger size (Reum, et al. 2023). Smart controls are particularly important in the operation of hybrid systems.

Heat pumps with smart controls that integrate thermal storage (water tank, thermal mass or battery) can offer flexibility by responding to electricity prices, with integrated rooftop PV, they can additionally maximise their self-consumption. Further flexibility can be provided through cluster control or flexible operation of large heat pumps in district heating and cooling (DHC) networks.

### How does a compression heat pump work?

The fan or heat collector sources low-temperature heat from the environment, which is then extracted by the evaporator using a refrigerant. The gaseous refrigerant is then compressed, raising its temperature, and this higher temperature heat is transferred via the condenser to air or water in the heat distribution system to provide space heating or hot water. Variable speed inverters allow the fan and compressor to run at different speeds depending on the demand, improving efficiency. Electronic controls provide the user interface, and semiconductors are also used in the compressors, pumps and fans themselves.

Heat pumps often incorporate a secondary heating technology as a backup in case of malfunction, to handle peak demand, or to capitalize on fluctuating energy costs. The most common back-up technology is an electric heater integrated in the heat pump itself. These heaters are typically used less than 5% of the time (Fraunhofer in (Nowak 2022)).

### Heat pump applications in buildings

Heat pumps provide efficient heating, cooling and hot water supply for buildings by using ambient heat sources, such as air, water and the ground. The market penetration of heat pumps is highest in new single-family buildings but are also more commonly installed in older buildings, apartment buildings, and non-residential buildings (EHPA 2023).

In existing single-family houses, heat pumps offer multiple benefits compared to boilers, such as increased efficiency, reduced greenhouse gas emissions, and lower operational costs. While new single-family houses are well insulated and allow heat pumps to work with the greater efficiency, existing houses vary in terms of thermal efficiency. Around 85% of EU buildings were constructed before 2000, and its estimated that around 75% of them are energy inefficient.[4] The efficiency of heat pumps is partly determined by the operating

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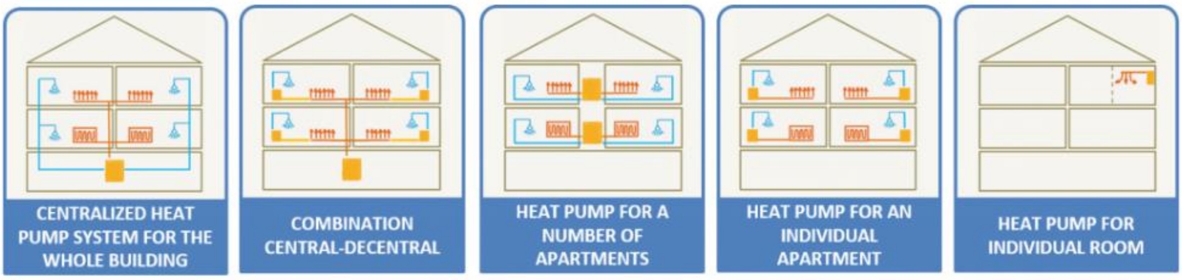
[4] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en.

temperatures of radiators; many older and less efficient homes require higher temperatures due to the size of the radiators and the overall heating demand.[5] For some of these houses, the heat pump might be installed in combination with a renovation measure such as insulation, replacement of radiators with larger ones, or hydronic balancing of the heating system. Nevertheless, research projects and experience show that even in a house with poor energy efficiency, a heat pump can work efficiently enough if the house has appropriately sized and well-installed radiators. Alternative options would be installing a hybrid system such as an air-water heat pump with a condensing gas boiler, a thermally driven heat pump or an electric heat pump designed to work at high temperatures.

Optimally selecting the type of refurbishment could improve the energy performance of the heat pump, leading to decreased operating and up-front costs. Moreover, to continuously improve the operating efficiency effective control systems and algorithms are needed. The performance of the heat pump is also influenced by the quality of the product itself. To ensure the heat pumps meet a certain quality, an appropriate product certification scheme could be beneficial. For heat pumps, the Heat Pump Keymark certification is required in several countries in order for a heat pump installation to qualify for subsidies.[6]

The installation of heat pumps in multi-family buildings still occurs less frequently (especially in older and larger apartment buildings) than in single-family houses. According to estimates from the European Heat Pump Association (EHPA), less than 10% of all heat pumps sold have a capacity of more than 20 kW (EHPA 2023). In new construction and building renovation, using heat pumps in multi-family houses is feasible, and there are already successful examples across Europe, in a range of configurations (Figure 1).

**Figure 1**: Concept groups of different solution possibilities of heat pump systems for multi-family houses



*Source: (IEA HPT, Annex 50+62, 2024)*

There are, however, still administrative (e.g. property rights) and technical barriers to more widespread implementation (IEA HPT, Annex 50, 2022). The first technical barrier is that many multi-family buildings in the EU were constructed before 1970 and either require building envelope refurbishment or operate at higher heating temperatures (>60°C). The second technical barrier is that multi-family buildings are often located in densely populated urban areas, making it challenging to access a geothermal heat source or find a suitable location for the outside unit of an air-source heat pump.

**Opportunities and challenges for heat pump deployment in buildings**

Using heat pumps in buildings presents a substantial opportunity for decarbonisation, particularly when integrated into existing structures through energy renovation, thereby unlocking the potential for carbon-neutral buildings. Furthermore, combining heat pumps with renewable energy sources (RES), such as solar or wind power, enables building owners and occupants to significantly reduce their reliance on fossil fuels, lower energy costs, and contribute to a more sustainable built environment. As a key component of smart buildings, heat pumps can interact with building management systems and other technologies in a more dynamic way, optimising energy efficiency, and enabling real-time monitoring and control of energy consumption, ultimately helping to meet the EU's ambitious climate change targets.

The adoption of heat pumps is hindered by several key barriers, including high upfront costs, uncertain operating costs, and a shortage of skilled installers. High electricity prices and limited availability of dynamic pricing also pose a challenge, as they prevent heat pumps from operating at their full potential and reduce

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5 Other parameters influencing heat pump performance are the temperature of the heat source (ambient, brine, water) and the quality of the installation (appropriate capacity, proper distribution, etc.).

6 https://keymark.eu/en/products/heatpumps/where-is-heat-pump-keymark-recognized.

their cost-effectiveness. Furthermore, the high demand for heat pumps in 2022 exposed a significant shortage of skilled labour in the industry, leading to delayed installations and extended waiting periods for consumers, which in turn has negatively impacted the overall growth of the heat pump market.

### What are the common industrial applications for heat pumps?

The industrial sector comprises a range of sub-sectors with diverse heating requirements, from those needing direct, very high temperatures for processes (such as steel, cement, glass, and non-ferrous metals), to those that use direct heat and steam (such as chemicals), to lower-temperature sectors where steam is the primary medium for process heating (including the pulp and paper, and food and drink industries). This diversity means that significant emissions reductions can only be achieved by deploying a multitude of solutions, including waste heat recovery and heat pumps. Industrial heat pumps are based on the inverse Organic Rankine Cycle and can upgrade lower-temperature heat sources, including industrial waste heat, into higher-temperature process heat. They tend to use screw, piston or turbo compressors. In terms of capacity, they can be factory-built and modular from 100 kW to 1 MW or tailor-made from 1 MW to 10 MW; large-scale heat pumps exist from 10 MW to 100 MW (Arpagaus 2023).

Heat pumps are the key technology for decarbonising industrial process heat below 250-300°C. For heat supply temperatures below 100°C, they are already a well-proven technology and being implemented (notably in food and materials drying, distilling, dairy production (pasteurisation) and paper) (IEA HPT, Annex 58, 2023). However, despite the availability and potential, it is not yet extensively used. In terms of potential, heat pumps for temperatures up to 100°C have the potential to cover 222 TWh/a, which represents 11% of the process heat demand in European industry (de Boer, et al. 2020).

For the majority of process heat requirements above 100°C, the available technologies are currently limited, although various technologies are under development (IEA HPT, Annex 58, 2023). In terms of potential, in the temperature range of 100-200°C, an additional 508 TWh/a (26%) of the total process heat demand can potentially be emissions-free (de Boer, et al. 2020). It is expected that various high-temperature heat pump technologies will become commercially available and implemented: up to 120°C by 2024 to 2025, up to 160°C by 2025 to 2026, and even higher temperatures by 2026 to 2027 (IEA HPT, Annex 58, 2023).

Several studies have analysed the application potential of heat pumps in the industry (cited in (IEA HPT, Annex 58, 2023):

- The total $CO_2$ abatement potential amounted to 86.2 Mt, which is equivalent to 17% of the energy-related $CO_2$ emissions of the EU for the industrial sector. Of this amount, 21.5 Mt was covered by economically feasible cases. However, it is important to note that this study limited the heat pump sink temperature to 100°C (Wolf and Bles 2016).
- The heat pump potential was calculated at an aggregated level, estimated to be 102 PJ in EU industries, with a focus on applications in the temperature range of 100-200°C (Kosmadakis 2019).
- The results indicate a potential cumulative heating capacity of industrial heat pumps in the EU of 23.0 $GW_{th}$, with 4 174 heat pump units capable of meeting 178 TWh/a of process heat demand (Marina, et al. 2021).
- Worldwide, approximately 30% of the low- and medium-temperature heat demand at up to 400°C should be covered by industrial heat pumps by 2050, and already half of it (15%) should be implemented by 2030 (IEA, 2021).

### Opportunities and challenges for heat pump deployment in industry

Existing challenges include a low level of awareness of heat pump technologies in the industry, fuel price volatility, policy uncertainty and a lack of funding for RD&I. Depending on how these challenges are overcome and the momentum created in the market, there could be a shortage of production capacity and skilled labour, particularly in production, installation and engineering consultancy.

Unlocking the massive market potential for industrial heat pumps offers a twofold advantage for European industries. Firstly, the European supply chain for industrial heat pumps is a global leader, and further investments in increased production capacities, standardisation and expanding the range of applications to higher temperatures will solidify this leading role in the future. Proper market development may make it one of Europe's next success stories. Secondly, massive implementation in the European market will significantly strengthen the European process industry. Production sites will become more efficient, leading to lower product costs and increased competitiveness, while reducing greenhouse gas emissions substantially. Electrification by heat pumps will enhance the independence of European countries from fossil fuel imports and energy imports in general.

**Heat pumps in district heating and cooling**

Large heat pumps already play a crucial role in DHC networks in some markets where they upgrade sources such as waste and renewable heat to a temperature suitable for heating and cooling buildings. There have been many examples of implementation across Europe. Two notable ones are in Denmark and Germany. In Denmark, the world's largest heat pump (60 $MW_{th}$) has been installed in Esbjerg, providing heating for 100 000 people.[7] In Germany, the largest heat pump in the country (24 $MW_{th}$) delivers district heat to 10 000 households, reducing $CO_2$ emissions by 15 kt per year.[8] Combined with thermal storage, electric boilers and cogeneration, they enable the integration of sustainable sources into the energy system and open up opportunities for sector integration. Additionally, they also maximise the decarbonisation potential of intermittent renewable electricity sources and bring flexibility and stability to the energy system.

Today, large heat pumps represent 2.5 $GW_{th}$ installed capacity in the DHC mix at the European level – or approximately 1% of the total, highlighting a large potential for further uptake. Based on the investment plans of some of the largest DHC networks in Europe, this capacity is expected to increase by over 80% by 2030, as the mix changes and the networks grow (EHP 2024).

Large heat pumps are versatile in their capacity to use a wide range of low-temperature heat sources, enabling energy diversification and accelerating the decarbonisation of heating. Upgrading the temperature levels of these sources enables the integration of renewable and waste heat in district heating systems. Combined with efficient and intelligent buildings, large heat pumps pave the way for high energy performance in DHC. The main energy sources that can be harvested thanks to large heat pumps include (EHP 2024):

- Renewable heat sources (geothermal and ambient energy);
- Waste heat from industrial processes;
- Urban excess heat (e.g. from supermarkets, metro systems or data centres[9]);[10]
- Sewage water treatment facilities.[11]

Heat pumps can be used in different parts of the district heat network and have various functions. Traditionally, heat pumps have been applied as base load heat generators, but there are seven common use cases of heat pumps within a district heating system (Gudmundsson 2024):

- Central heat pump – base or mid-load source;
- Semi-centralised heat pump – temperature boosting at neighbourhood level (temperature zoning);
- Decentralised heat pump – temperature boosting for critical buildings;
- Decentralised heat pump – temperature boosting for domestic hot water (DHW) demands;
- Decentralised heat pump – DHW circulation heat pump (maintain the circulation temperature and securing a low return temperature from the DHW service);
- Decentralised heat pump – Comfort cooling heat pump (using the network as a heat sink for waste heat from cooling the building);

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[7] The 60 MW seawater heat pump system will run together with a new 60 MW wood chip boiler based on 100% sustainable wood chips and a 40 MW electric boiler plant (for peak and back up load), see www.man-es.com/docs/default-source/document-sync/esbjerg-heat-pump-reference-case-eng.pdf?sfvrsn=45a29f76_5.

[8] www.enbw.com/unternehmen/presse/grosswaermepumpe-liefert-fernwaerme-fuer-10-000-haushalte.html.

[9] As the world becomes increasingly digitalised, data centres and data transmission networks are emerging as an important source of energy demand. According to the IEA (September 2022), data centres alone account for 1-1.5% of global electricity use. In Europe, data centres tend to locate in places where data transmission networks are most efficient. These installations are increasingly seen also as potential partners for waste heat projects.

[10] The ReUseHeat project estimates that urban waste heat sources could cover about 10% of EU heat demand.

[11] An example of Eneco Utrecht case (27 MWth): www.eneco.nl/en/about-us/what-we-do/sustainable-sources/heat/heat-pump-at-utrecht-sewage-treatment-plant/.

- Decentralised heat pump – Temperature boosting for DHW and space heating demands.

Combined with large thermal storage, electric boilers and cogeneration, heat pumps in DHC help reduce the overall electricity demand for heating and cooling. In the context of electrifying many uses, they will further contribute to freeing up capacity for other sectors such as transport and industry. The reduction of peak demand will reduce the level of investment necessary in the grid and peak-production units.

Together with city-scale thermal storage, large heat pumps can absorb excess renewable electricity (for direct or postponed use) and modulate production to ensure grid balancing (thanks to the quick ramp-up or ramp-down of generation) as well as providing weekly and even seasonal flexibility.

The primary factors driving the implementation of large heat pumps in DHC are the various measures being applied to the overall deployment of such networks. These measures include heat planning, aid for infrastructure deployment, building standards, and acceleration of permit procedures. Additionally, a ban on new fossil boilers has proven an effective instrument, with several Member States having implemented or announced the phase-out of gas or oil boilers.

Electricity prices and taxation applicable to electricity will impact future developments. Energy taxation should be reviewed to stop favouring gas and oil heating. The implementation of tax cuts for electricity used to drive large heat pumps in some countries (e.g. Sweden, Finland) has proven to be effective.

The fast deployment of new projects will also rely on the ability of manufacturers to overcome recent challenges that affected production (increasing prices for materials, shortages of key components and skilled labour). Recent announcements of new investments from key leading companies in the heat pump sector are encouraging signs of trust in future market developments. Appropriate measures and incentives will be needed at the EU, national and regional levels to decrease the cost of large heat pump deployment and support the expansion and modernisation of the related heating and cooling network infrastructure.

## 2.1 Technology Readiness Level

The main heat pump technologies are mature, with a Technology Readiness Level (TRL) of 9 (Table 2).[12] There are also promising technologies at lower TRLs. Note that development status in practice depends on TRL, but also other factors such as efficiency, cost and availability.

Although heat pumps can be installed in buildings with all different insulation levels, they work best in those with high energy performance and low feed-in temperature requirements (55°C or less). The smaller the difference between the energy source and the desired temperature in the building, the higher the efficiency (and the smaller the heat pump size). Making heat pumps cost-effective even in less well-insulated buildings, partly by reducing the up-front investment cost and partly by improving the efficiency and extending the operating range, is therefore an important area for RD&I.

An important part of that is improving performance at very low ambient temperatures. Recent heat pump models can be used in areas with extended periods of sub-freezing temperatures, down to around -20°C. Design innovations for low ambient temperatures include higher capacity and pressure, and improved materials.

High-temperature heat pumps with supply temperatures up to 160°C is commercially available, though performance and cost need to be improved further. Prototypes are being tested up to 200°C[13] , and ongoing research shows viability up to 280°C (Zuehldorf, et al. 2019). Upgrade to 400°C is being researched at TRL 3-4 but is not yet commercially viable (EC 2020).

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[12] Apply for heat pumps that are designed for operating with a heat supply temperature lower than 160°C

[13] See for example the Danish project, www.suprheat.dk.

**Table 2.** Technology Readiness Levels by heat pump type or sector

| **Sub-technology** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|
| Air-air | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 |
| Air-water | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 |
| Ground-source | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 |
| Water-source | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 |
| Gas-driven | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | ▨ |
| Industrial and DHC* | 🟦 | 🟦 | 🟦 | 🟦 | ▨ | ▨ | ▨ | ▨ | ▨ |
| Membrane | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | ▨ | | | |
| Thermo-acoustic | 🟦 | 🟦 | 🟦 | 🟦 | | | | | |
| Transcritical thermal compression | 🟦 | 🟦 | 🟦 | 🟦 | | | | | |
| Caloric | 🟦 | 🟦 | ▨ | ▨ | | | | | |

| | |
|---|---|
| **Technology Readiness Levels** | |
| *Research* | |
| 1 | Basic principles, ideas observed and reported |
| 2 | Technology concept or application has been formulated |
| 3 | Concept validation, experimental proof of concept |
| *Development* | |
| 4 | Technology validated in lab |
| 5 | Technology validated in a relevant environment |
| 6 | Prototype demonstrated in a relevant environment |
| *Deployment* | |
| 7 | Prototype demonstrated in operational environment (pre-commercial scale) |
| 8 | Actual system fully qualified and tested |
| 9 | Product ready for the market |

*Source: Various, including Hofmeister and Guddat (2017).*

** For industrial and DHC heat pumps, the TRL depends on the supply temperature, from less than 90°C (highest TRL) to 280°C (lowest).*

Areas of innovation include hybrid systems; integration with other systems such as ventilation, hot water, air conditioning, storage and solar thermal; size reduction; noise reduction, e.g. through insulation or design; industrial, large building, and DHC applications; new business models such as heat-as-a-service; electrochemical compressors; 3D-extruded components; and generation of cold at temperatures below freezing by water-based absorption and adsorption processes.

Optimisation to provide both heating and cooling is an important market trend across heat pump types, in part because of global warming (Congedo, et al. 2023). Cooling is only 1% of heating and cooling final energy consumption currently, but cooling degree days in 2022 were almost three times higher than in 1982 (Eurostat, 2023a). As warming continues, cooling demand in the EU could increase by 50% between 2020 and 2030 and nearly double by 2040 (Eurostat cited by EGEC). In some cases, reversible heat pumps can increase the efficiency and profitability of DHC networks by providing both heating and cooling services throughout the year.

The prioritisation of these research needs varies somewhat by heat pump type. For example, ground-source heat pumps have high up-front costs and low operating costs, and so would benefit from new business models or financial support schemes, or improvements in technical solutions such as shared boreholes and ground loops.[14]

When it comes to the refrigerant, several hundred designs of heat pumps that use hydrocarbons such as propane or isobutene, from about 48 different manufacturers, are commercially available in Europe (ATMOsphere 2023). The basic RD&I to optimise heat exchangers and compressors to use low-GWP

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[14] See for example https://theconversation.com/no-space-for-a-heat-pump-heres-how-your-whole-street-could-get-off-gas-heating-180005. For large heat pumps, Heat Purchase Agreements have been implemented in the agri-food sector in particular.

refrigerant has been done, but research is still needed in order to ensure safety, safe end-of-life disposal, and to comply with the F-Gas Regulation.[15]

Completely different types of heat pumps are also being developed but will need time to be commercialised. They are unlikely to have an impact before 2030 but could become important technologies thereafter because they can use less electricity or avoid the need for a refrigerant altogether. For example:

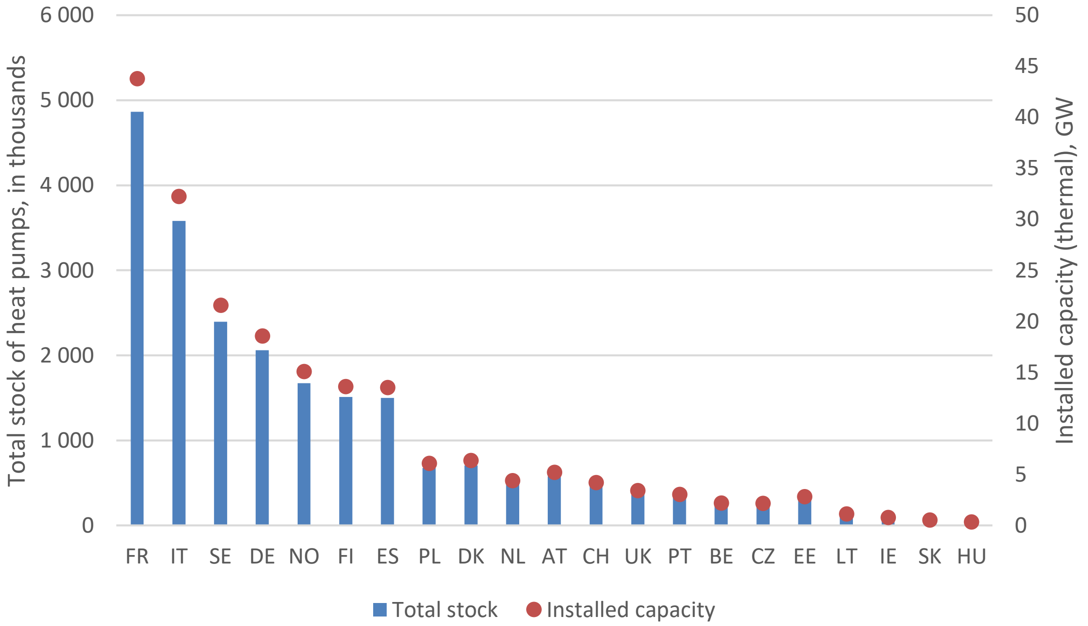
- Caloric heat pumps use solid-state materials that have a caloric effect, i.e. magnetocaloric, elastocaloric, electrocaloric or barocaloric (Schipper, et al. 2023). Magnetocaloric heat pumps, for example, produce temperature change by variation of magnetic field. They can achieve high efficiency, have no moving parts, operate silently and avoid the need for refrigerants, but need more RD&I to become competitive.[16]
- Thermo-acoustic heat pumps work by compressing and expanding helium, and could use 20% less electricity; also for industrial applications.[17]
- Transcritical thermal compression heat pumps for the residential sector (such heat pumps are more often used for water heating in large buildings).
- Membrane heat pumps are at the prototype stage.

## 2.2 Installed energy capacity, sales and generation

### 2.2.1 Installed capacity and production

21.5 million heat pumps had been installed in the EU by 2023.[18] Around 50% of the heat pumps sold in 2023 were hydronic (air-water and ground source), followed by air-air (33%), sanitary hot water (13%) and others (3%). It is estimated that in 2022, the installed capacity was 172.5 $GW_{th}$, producing 322.7 TWh of useful energy, of which 203.6 TWh was renewable (EHPA 2023). In 2023, the highest number of heat pumps were installed in France, followed by Italy, Sweden and Germany (see Figure 2).

**Figure 2**: Installed heat pumps (left) and capacity (right) in European countries in 2023



*Source: Total stock (EHPA 2023), Installed capacity: own estimation and (EHPA 2023)*
*Note: Installed capacity was estimated assuming an average heat pump of 9 kW.*

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[15] See for example www.ise.fraunhofer.de/en/research-projects/lc-150.html.

[16] RES4BUILD (https://res4build.eu/) is one Horizon 2020 project looking to improve the performance of magnetocaloric heat pumps.

[17] See for example www.blueheartenergy.com or www.equium.fr.

[18] EHPA data covering 18 Member States (FR, IT, SE, DE, ES, FI, PL, DK, NL, AT, PT, BE, CZ, EE, LT, IE, SK, HU)

Approximately 60 million heat pumps have been installed globally. (IRENA 2024). According to the IEA, the installed capacity of heat pumps exceeds 1 000 $GW_{th}$), with heat pumps covered around 9% of world heating demand (IEA, 2022).

### Heat pumps in buildings

The main use of energy by households in the EU in 2022 was for heating their homes (63.5% of final energy consumption in the residential sector), with renewables accounting for 31.4% of EU household space heating. Despite heat pumps (ambient heat) currently making up only 5% of the total consumption for heating and hot water (Eurostat 2024), they are the second most-used renewable technology and account for the largest relative growth among renewables in the heating and cooling sector in the EU over the period 2020-2030. All Member States expect to see an increase in heat pumps over that period in their National Energy and Climate Plans (NECPs) submitted in 2019 (Toleikyte, 2021).

According to the European Heating Industry (EHI), in 2021, heat pumps represented a mere 6% of the total hydronic space heating systems implemented, whereas gas boilers maintained a significant market dominance, representing 71% of installations. Since then, data from the EHPA has shown a 57% increase in the sales of air-water heat pumps between 2021 and 2023, indicating a rapidly growing market.

Nevertheless, the use of heat pumps to supply heat and domestic how water (DHW) has increased sharply over the last decade. According to Eurostat data, the share of ambient heat (heat pumps) in total EU energy consumption for space heating and hot water in households increased from 1.7% in 2017 to almost 5% in 2022.

**Figure 3**: Share of ambient heat (heat pumps) in the total household's energy consumption for space heating and hot water in the EU.

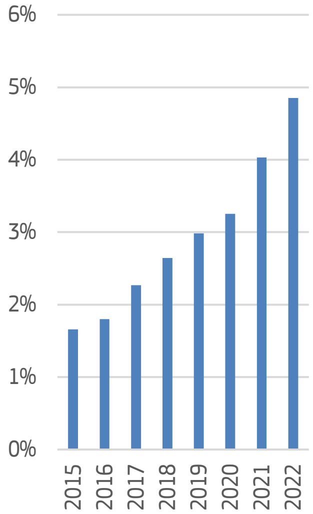
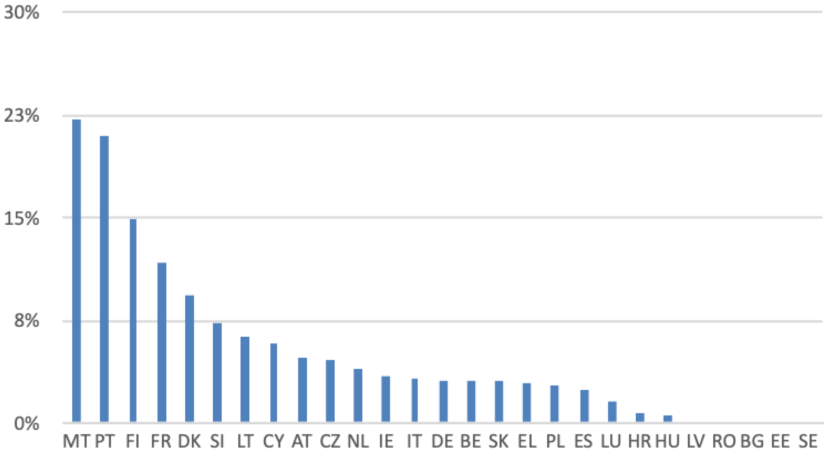


**Figure 4**: Share of ambient heat (heat pumps) in the total household's energy consumption for space heating and hot water in the EU Member States in 2022.

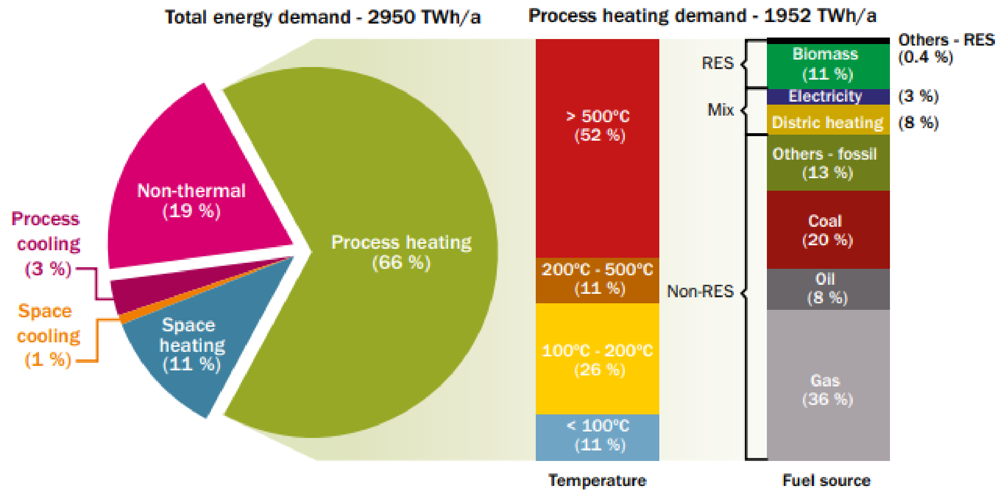


*Source: Eurostat 2024*
*Note: Data for EE and SE are not available.*

### Heat pumps in industry

In 2020, fewer than one million heat pumps were installed in the industrial sector worldwide (IRENA, 2023a). In Europe, the industry sector was responsible for 25.1% of final energy consumption in 2022. Electricity (33.3%) and gas (31.2%) accounted for nearly two-thirds of final energy consumption in the sector. The highest share of energy is being used for process heat (60%) (Eurostat 2024). When categorising process heat into temperature levels, Figure 5 shows that low temperatures (<200°C) accounted for 37% of process heat demand, while high temperatures (>200ºC) accounted for 63%. The industrial heat demand is primarily met by fossil fuels. Within the industry sector, the largest energy consumers in the EU in 2022 were chemicals and petrochemicals (plastics), non-metallic minerals and paper, pulp and printing.

**Figure 5:** Final energy demand in European industry (left) and process heating demand by temperature level (right) in 2019

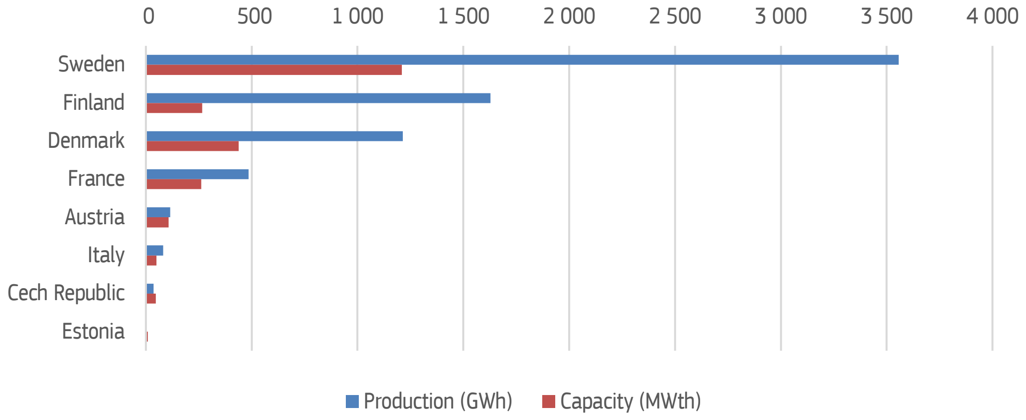


*Source: Eurostat 2019 and Fleiter 2017 cited in SINTEF 2020.*

### Heat pumps in district heating and cooling

The installed capacity of large heat pumps in DHC networks in Europe was identified as 2.5 $GW_{th}$ in 2021 by Euroheat & Power (EHP). This represents around 1% of the total installed DHC capacity in Europe (EHP 2022). Based on the investment plans of some of the largest DHC operators in Europe, this capacity is expected to increase by over 80% by 2030. Today, with a share of 2%, heat pumps and electric boilers represent nearly 10 TWh of district heat supply (EHP 2024).

**Figure 6**: Large-scale heat pumps in district heating



*Source: EHP 2022*

Large heat pumps play a crucial role in decarbonising DHC as they enable the use of low-temperature heat sources, opening the way for the deployment of more efficient 4th and 5th generation DHC. The Heat Roadmap Europe project estimates that approximately 25-30% of installed capacity could be based on large electric heat pumps by 2050.[19] The ReUseHeat project identified the potential of using low-temperature waste heat with heat pumps such as wastewater treatment plants and data centres.[20] The project estimated that accessible sources of low-temperature waste heat located inside or within 10 kilometres of existing DHC

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[19] https://heatroadmap.eu/

[20] https://cordis.europa.eu/project/id/767429

networks could represent over 300 TWh/y, or about 12% of the total European heat demand for buildings (EHP 2024).

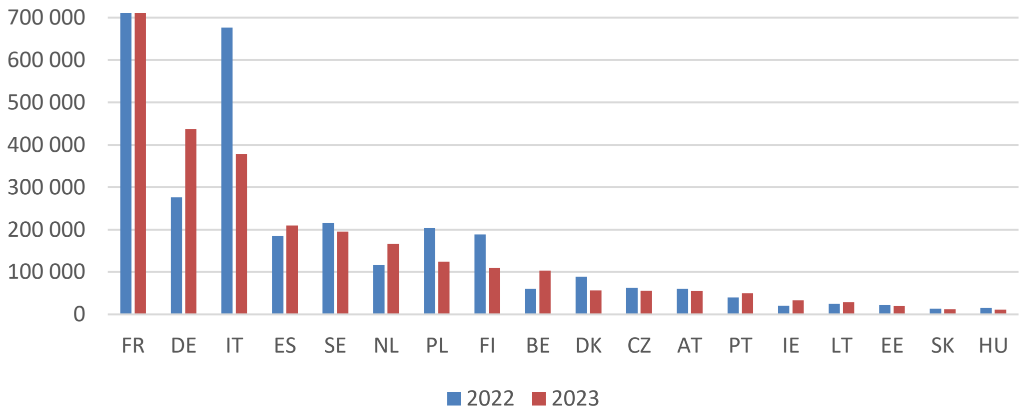
### 2.2.2 Sales

Between 2013 and 2022, heat pump sales in the EU experienced continuous growth, reaching a peak in 2022 when they increased by 42% compared to the previous year. However, 2023 saw a slowdown, with a drop of 7% compared to the record in 2022. The 2.8 million heat pumps sold in 2023 brought the total installed stock to around 21.5 million.

The main reasons for the slowdown were a dip in gas prices, the overall economic context (construction activity, interest rates, inflation), and policy uncertainty at the EU and national levels. Most of these factors are not exclusive to Europe. Global heat pump sales decreased by 3% in 2023, with the major markets showing negative trends. Sales in Japan and the United States fell by 10% and 15%, respectively. China was the exception with a growth of 12%. According to the industry associations (EHPA, 2024 and EHI, 2024), the main reasons for the slowdown in the EU are the shift in energy prices, the general stagnation of the economy, the polarisation of the political debate around the energy transition and the stop-and-go practice for financial incentives across Europe to lower the purchase price of heat pumps.

The sales data by Member States indicate that France had the highest sales in 2023 (over 720 000 heat pumps), Germany (over 430 000), and Italy (over 370 000) (Figure 7). Several markets experienced a considerable increase in 2023, including Germany (59%), The Netherlands (43%), Belgium (72%), and Ireland (63%). The most significant sales decreases occurred in Italy (-44%), Finland (-42%), and Denmark (-36%) (EHPA, 2024).

**Figure 7**: Heat pump sales in 13 Member States in 2022 and 2023

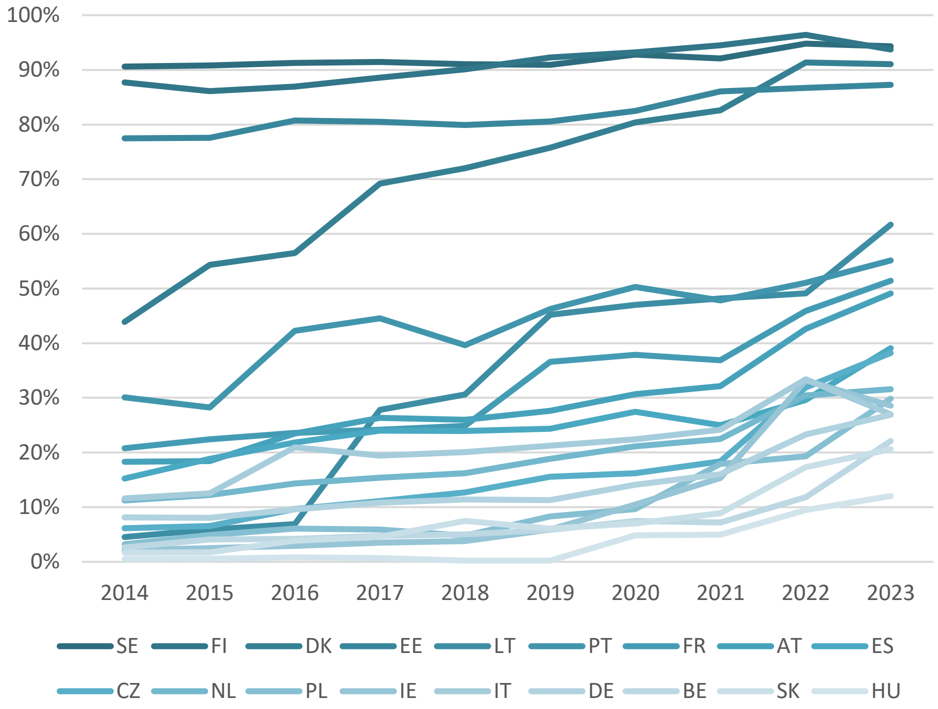


*Source: Based on EHPA 2024.*

The most sold heat pumps in 2023 were air-water (45%), followed by air-air (33%), heat pumps for DHW (13%), and ground-source heat pumps (5%). Hybrid heat pumps have gained popularity in certain markets. According to the EHI, almost 11% of all heat pumps sold in 2022 were hybrid (the data cover only hydronic heat pumps). The largest markets for hybrid heat pumps were Italy and the Netherlands, accounting for 90% of total sales. As with air-water heat pumps, sales of hybrids experienced a slowdown in 2023.

Figure 8 depicts the expansion of heat pump market share across 18 Member States. While heat pumps have been the most popular choice in the Nordic countries for several years, the market share in other countries is rapidly increasing from lower levels (EHPA 2024).

***Figure 8:*** *Market share of heat pumps for space heating by EU country (i.e. heat pump sales as a portion of the total heat pump and boiler sales)*



*Source: EHPA, 2024.*

In 2022, industrial heat pump sales in Europe reached 2 618 units, marking a substantial 171% increase from the previous year (EHPA, 2023); yet, a subsequent decline was observed in 2023, with total sales dropping to 1 354 units (EHPA, 2024).

### 2.2.3 Deployment needs and projections

In order to limit the global temperature rise to 1.5°C, the IRENA Roadmap to Net Zero suggests that nearly 800 million additional heat pump units need to be installed globally by 2050 (IRENA 2023). This represents a 14-fold increase from the roughly 60 million units installed today, paving the way for a significant scale-up of grid services provided by this highly efficient heating technology.

For the EU, according to JRC analysis of 11 scenarios that align with the EU's long-term vision (i.e. near-zero emissions in the EU by 2050 compared to 1990) show a key role for heat pumps in buildings (Nijs, Tarvydas and Toleikyte 2021). In 2030, all scenarios see an increase in ambient heat demand, from a modest 50% increase to a tripling. In 2050, ambient heat becomes one of the main energy sources for heating and hot water preparation, providing on average at least 40 million tonnes of oil-equivalent (Mtoe) across all scenarios. This will be driven in particular by a switch from fossil fuel boilers to low-carbon alternatives, mostly heat pumps.

Heat pumps are one of the key technologies enabling the clean energy transition and achieving the EU's carbon neutrality goal by 2050. Moreover, it is one of the key technologies to make the EU independent from Russian fossil fuels. With the REPowerEU plan, the European Commission expects the installation of 30 million hydronic heat pumps by 2030. REPowerEU aims to frontload the deployment of heat pumps compared to the Fit-for-55 targets. Thus, 10 million hydronic heat pumps will be added in the next five years, with 20 million additional units by 2030.

The Net-Zero Industry Act (NZIA) sets a manufacturing capacity target for heat pumps of 31 GW a year by 2030. This number is, however considerably lower according to the industry (EHPA and EHI), compared to the RePowerEU ambition to install 30 million new hydronic heat pumps by 2030. The EHPA suggests that even in a conservative growth scenario, manufacturing capacity could reach around 47 GW annually by 2030.

Several NECPs highlight heat pumps as the main contributor to the share of renewables in heating and cooling.[21] The JRC analysis of the NECPs submitted by Member States in 2019 shows a significant increase in heat pumps across all countries, with the highest increase in Spain, followed by Hungary, Belgium and Poland. The highest amount of ambient heat from heat pumps is projected to be in Italy (5.7 Mtoe), followed by France (4.5 Mtoe) by 2030. These projections may vary in the updated NECPs submitted this year. Here are some country examples from the latest NECPs, showing plans and national scenario results for heat pumps:

**Germany:**[22] Heat pumps are the key technology for renewing decentralised heat production. The BMWK[23] has therefore launched a major heat pump offensive in summer 2022 and has since been working with a broad coalition of industry, industry, crafts, trade unions and academia in the framework of the heat pump summits on the objective of at least 500 000 heat pumps every year from 2024.

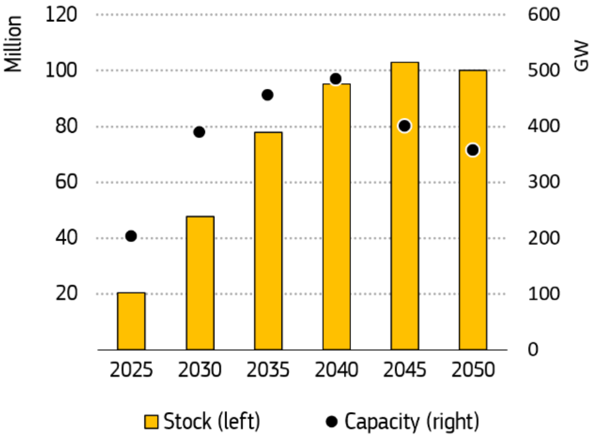
**France:**[24] Public support for developing the French heat pump sector will enable the production and installation of one million heat pumps each year by the end of 2027.[25] Air-water heat pumps will mainly be installed as a substitute for gas or oil boilers. Support will be provided to develop heat pump technologies in collective housing to replace gas boilers. Legislative simplification will be adopted to facilitate the installation of heat pumps in collective housing, allowing derogation from local urban planning. A centre of expertise on heat pumps will be set up by 2025, with the financial support of the State, with the task of informing and equipping all building professionals.

**Italy:**[26] The plan foresees strong growth of heat pumps for heating and cooling. Scenarios for the period 2021-2030 show that in the residential sector, emissions are reduced by 32% due to the significant renovation rate of buildings, ongoing efficiency improvement, and the progressive electrification of the sector mainly due to the massive penetration of heat pumps.

### EU projections based on the POTEnCIA CETO 2024 Scenario

POTEnCIA (Policy Oriented Tool for Energy and Climate Change Impact Assessment) is a modelling tool developed by the JRC that allows a robust assessment of the impact of different policy futures on the EU energy system. The POTEnCIA CETO 2024 scenario is a deep decarbonisation scenario that follows a trajectory for EU's net GHG emissions aligned with the general objectives of the European Climate Law (see Annex 3 for more info on the POTEnCIA model and scenario). The POTEnCIA CETO 2024 scenario for the EU shows increased heat pump stock until 2045 (Figure 9).

**Figure 9**: Stock and capacity of individual heat pumps in the residential and service sector in EU, 2025-2050



*Source: JRC POTEncia.*

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[21] Under the Governance Regulation, Member States had to submit their final updated NECPs for the period 2021-2030 to the Commission by 30 June 2024 (draft by 30 June 2023). The national plans outline how the EU countries intend to address the five dimensions of the Energy Union.

[22] https://commission.europa.eu/document/download/c589deb5-9494-4984-9ef5-8e2ee711aaf2_en?filename=GERMANY-%20DRAFT%20UPDATED%20NECP%202021-2030%20EN.pdf.

[23] Bundesministerium fuer Wirtschaft und Energie (Federal Ministry for Economic Affairs and Climate Action).

[24] https://commission.europa.eu/document/download/ab4e488b-2ae9-477f-b509-bbc194154a30_en?filename=FRANCE%20%E2%80%93%20FINAL%20UPDATED%20NECP%202021-2030%20%28English%29.pdf.

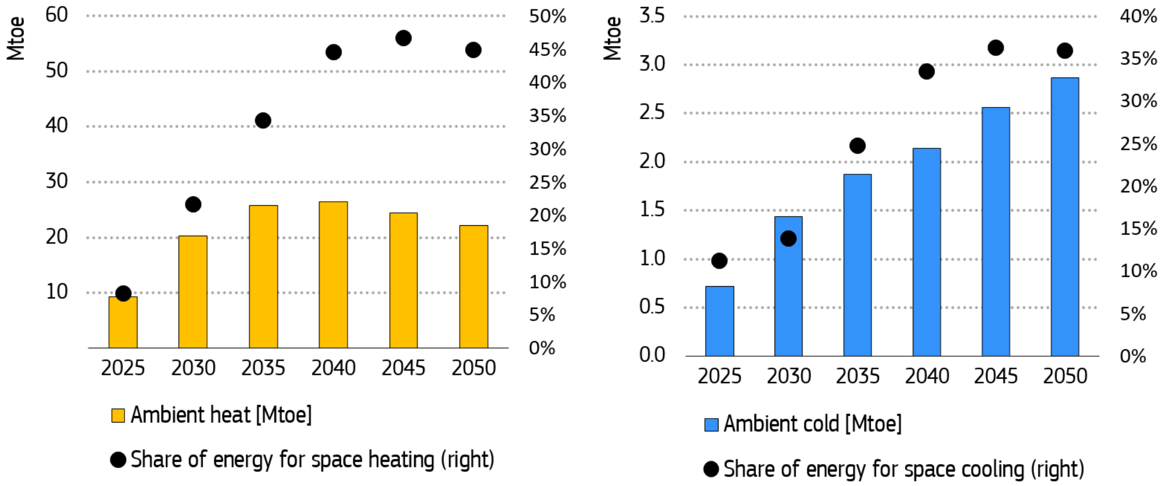
[25] Also see: https://presse.economie.gouv.fr/plan-daction-pour-produire-1-million-de-pompes-a-chaleur-en-france/.

[26] https://commission.europa.eu/document/download/5ef1819e-1c42-446f-91d0-abb9cf7719e8_en?filename=IT_FINAL%20UPDATED%20NECP%202021-2030%20%28English%29_0.pdf

The model results show that heat pumps installed in the residential and services sectors in 2025 cover 9% of the total energy provided for space heating (Figure 10 left). Installation increases to over 100 million heat pumps by 2045, making up the share of almost 50% of space heating services . The highest relative increase is expected between 2025 and 2030 due to the large penetration of heat pumps following European policies (the targets of Fit-for-55 in the mid-term and climate neutrality in 2050 in the long-term). However, the heat pump stock is projected to flatten out by 2050, with total capacity decreasing after 2045. This is a consequence of building efficiency improvements. As buildings become more efficient and better insulated to meet energy efficiency targets, the required heat per building will decrease, resulting in smaller heat pumps needed per household.

Reversible individual heat pumps also provide space cooling (Figure 10 right). It is estimated that these reversible heat pumps (ambient cold) will account for more than 14% of energy provided for space cooling by 2030. The role of heat pumps in providing ambient cold is projected to increase, reaching over 35% of the total space cooling provided by 2050.

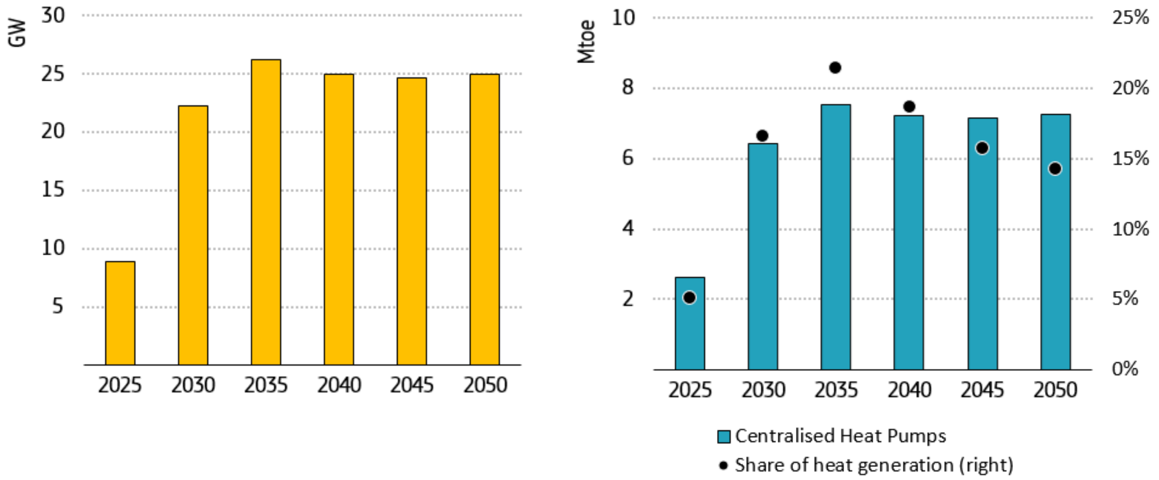
**Figure 10**: Ambient heat and share of energy for space heating (left) and ambient cold and share of energy for space cooling (right) of individual heat pumps in the residential and service sector in the EU



*Source: JRC POTEncia*

The capacity of centralised heat pumps for DHC is projected to increase by 150% from 2025 to 2030 in the EU, rising from 9 GW to over 22 GW (see Figure 11). The projected amount of ambient heat is expected to reach 3 Mtoe in 2025, covering 5% of the total heat generation for DHC. By 2030, the projected ambient heat is set to experience a significant increase to over 6 Mtoe, covering 17% of the total heat generation for DHC.

**Figure 11**: Capacity of centralised heat pumps for district heating (left figure) and ambient heat from centralised heat pumps (right figure, left side) as well as share of heat generation (right figure, right side) in the EU



*Source: JRC POTEncia*

## 2.3 Technology costs

### Up-front cost and operational cost

The up-front cost of a heat pump depends on various factors, such as the type of heat pump, its size or capacity, brand and the country in which it is being sold. The table below shows equipment and installation costs for different types of heat pumps. Equipment costs can vary widely, starting from around EUR 75 to as much as EUR 1 000, per installed kW, depending on the type and quality of the equipment (Danish Energy Agency and Energinet 2020). For a single-family house, an air-water heat pump (the equipment alone) amounts to EUR 989 per installed kW capacity. Assuming an average size for a heat pump for a single-family house is 7 kW, the air-water heat pump would cost approximately EUR 11 000 (EUR 7 000 plus installation cost of approximately EUR 4 000).

**Table 3:** Up-front cost of various heat pump types for single-family houses and apartment buildings

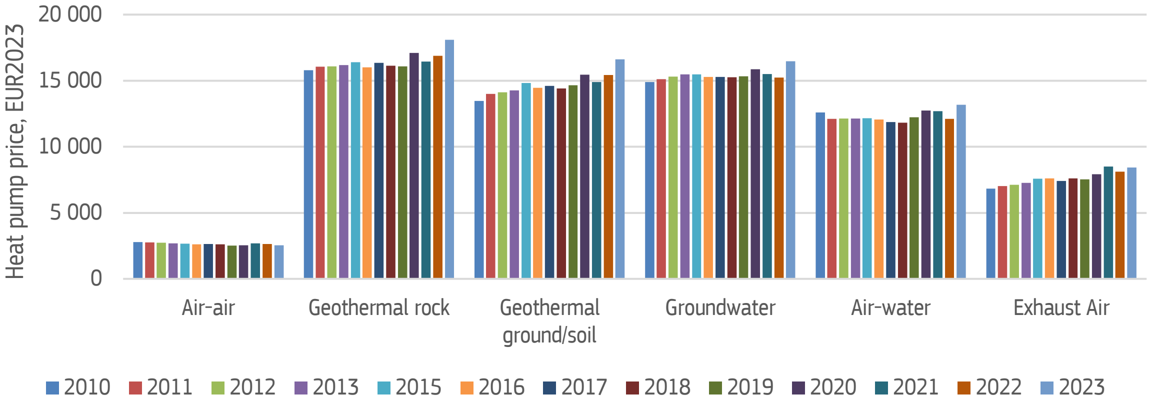
| | **Equipment costs, EUR/kW in 2020 prices** | **Installation costs, EUR/kW in 2020 prices** |
|---|---|---|
| Air-air | 75 | 0 |
| Air-water (single-family house) | 989 | 576 |
| Air-water (apartment building) | 562 | 126 |
| Ground-water (single-family house) | 1 009 | 1 064 |
| Gas boiler (single-family house) | 195 | 84 |
| Gas boiler (apartment building) | 55 | 14 |

*Source: (Danish Energy Agency and Energinet 2020).*

In the Swedish market, the cost of all heat pump categories has seen a consistent upward trend from 2010 to 2023. Annual surveys conducted with heat pump sellers and installers indicate that the price increase observed between 2022 and 2023 for all heat pump types was mainly driven by inflation. A significant price increase of 19% is reported for air-water heat pumps, while geothermal heating saw a price increase of 17%. Exhaust air heat pumps increased by 14% and air-air heat pumps by 6%. The estimate is based on an installer's survey, with 50 responses taken into account for 2023.

The prices in Figure 12 have been inflation-adjusted (2023 prices), showing that the price of air-air heat pumps remained stable with a gradual decrease from 2010 to 2023. The price for air-water heat pumps has increased over time, reaching its peak in 2023. The survey does not provide any reason for this increase. However, it observes that the increase in price in 2019 probably occurred due to the increasing prices for refrigerants. Similarly, the price for ground-source heat pumps has also increased. One of the reasons for this is that customers tend to drill deeper to adequately dimension the heat pump to cover the entire energy demand. The launch of several new models with potentially higher prices might have an impact as well.

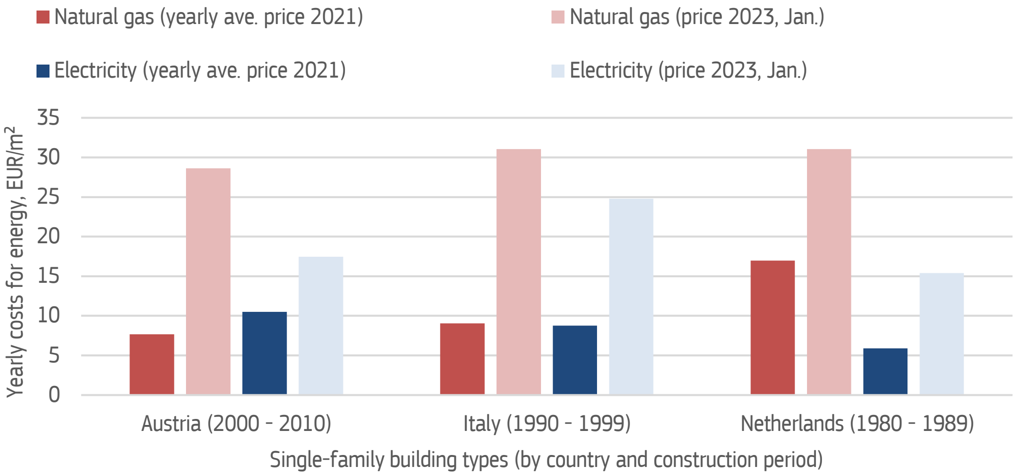
**Figure 12**: Price development of various heat pumps types, Sweden



*Note: Insights from a Swedish annual survey with heat pump installers and experts, 2010-2023. The prices are adjusted for inflation-and given in EUR 2023 prices. Source: adapted from* [*https://skvp.se/skvpold/statistik/pulsen/2023*](https://skvp.se/skvpold/statistik/pulsen/2023)

Operating cost depends on parameters such as the electricity consumption of the heat pump and the electricity price. The electricity consumption of the heat pump is also influenced by various parameters, such as the building's heat load. Figure 13 shows the energy costs for three single-family houses and compares the running costs of a gas boiler and an air-water heat pump. The figure also considers different electricity and gas prices, including the yearly average price in 2021 and the price in January 2023. The yearly running costs varied significantly in this period with volatile prices. For example, the single-family house in the Netherlands would pay almost EUR 6 per m² of heated floor area at the 2021 average price and EUR 15 per m² of heated floor area at the price from January 2023.

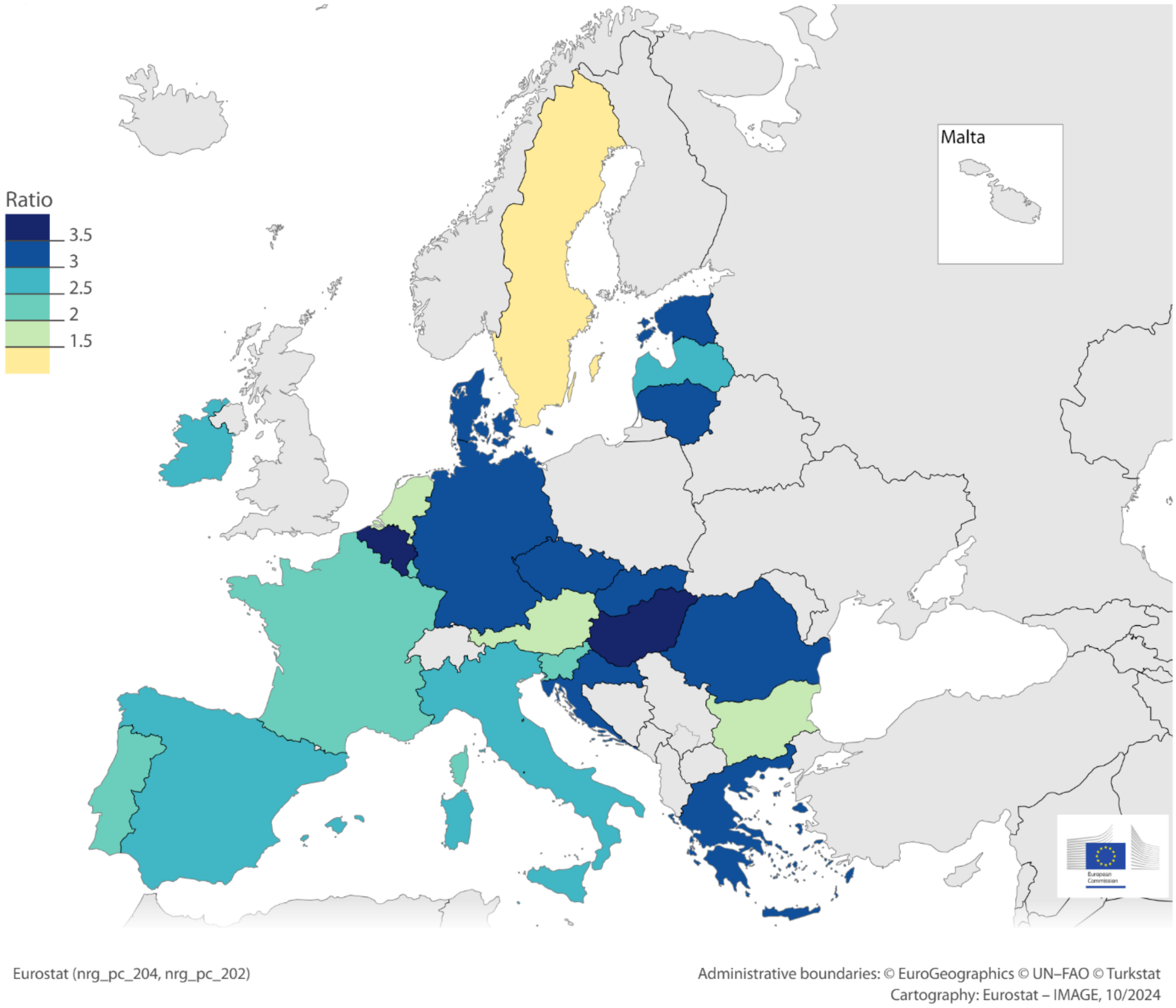
**Figure 13**: Running costs of heat pump and gas boiler in single-family houses located in Austria, Italy and the Netherlands



*Source: (Toleikyte, et al. 2023)*

The electricity-gas ratio is a crucial factor determining the cost-effectiveness of a heat pump in comparison to a gas boiler. In many EU countries, the electricity price is much higher than the gas price (Figure 14). The red colour indicates the countries where the consumer electricity price was more than 3.5 times higher than the consumer gas price (average price from the first quarter of 2024). Typically, electric heat pumps are two to five times more efficient than gas boilers.

**Figure 14**: Electricity-gas ratio for households in EU Member States. Prices for 2024 S1



Eurostat (nrg_pc_204, nrg_pc_202)

Administrative boundaries: © EuroGeographics © UN–FAO © Turkstat
Cartography: Eurostat – IMAGE, 10/2024

*Source: JRC based on Eurostat, 2024.*

### Levelised costs of energy

Figure 15 shows the levelised costs of heating a selected building in the Netherlands. It illustrates the levelised cost over the technical lifetime of the technology, broken down into the investment cost, operations and maintenance and fuel costs, and divided by total delivered energy (heat supply). Furthermore, it considers the cost of emitted greenhouse gas emissions, assuming a price scenario ranging from EUR 25/t$CO_2$ to 50/t$CO_2$ for gas boilers, as a consequence of the new Emissions Trading Scheme (ETS 2) for building and transport sectors that comes into effect in 2027.[27]

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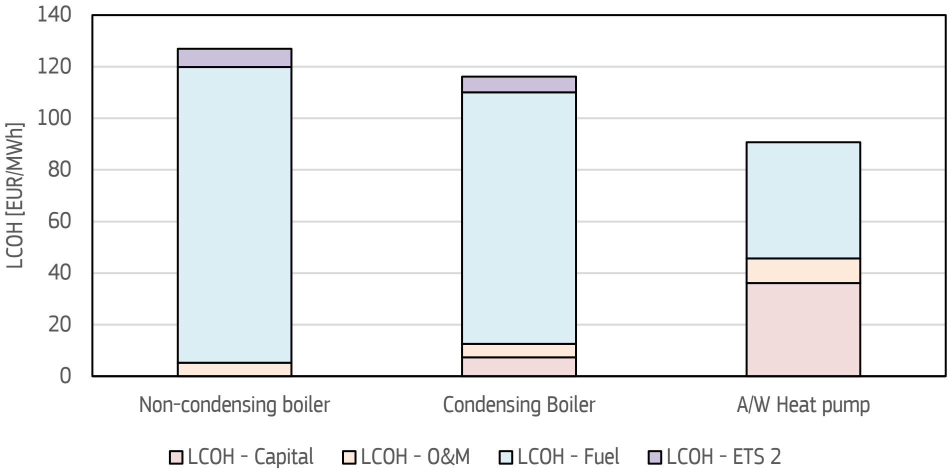
[27] https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/ets2-buildings-road-transport-and-additional-sectors_en.

**Figure 15:** Levelised costs of heating (LCOH) for a typical single-family house in the Netherlands.



*Source: JRC analysis for an upcoming report analysing the impact of the new ETS 2, which is covering heat fuels in buildings, on households.*

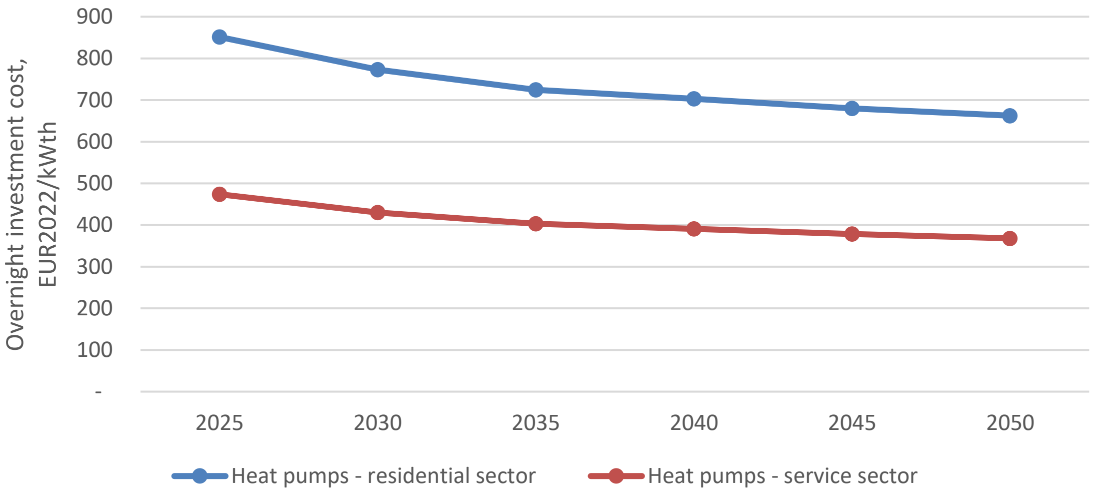
*Note: The LCOH measures the average cost per unit of energy produced by a power plant over its lifetime, taking into account installation, operation, and maintenance costs. The figure also includes an indicative ETS 2 price ranging from EUR 25 - EUR 50/tCO$_2$. The example building is a single-family house located in the Netherlands with non-condensing boiler, condensing boiler and air-water heat pump*

## Cost development

Investment costs are projected to decrease from 2025 to 2050 (see Figure 16), according to the *Global CETO 2°C scenario 2024* calculated with the POLES-JRC model. Generally, investment costs in the services sector are assumed to be lower than those in the residential sector, as economics of scale favour larger installations for service buildings. The scenario projects a decrease of approximately 22% in investment costs for heat pumps in both the residential and service sectors by 2050, compared to 2025.

A short description of the *Global CETO 2°C scenario 2024* and the POLES-JRC model can be found in Annex 3. Detailed information and assumptions on the heat pump related modelling approach are provided in a dedicated chapter in the CETO report *Impacts of enhanced learning for clean energy technologies on global energy system scenarios* (Schmitz, et al. 2024).

**Figure 16**: Investment costs development for heat pumps in residential and service sector 2025-2050 (*Global CETO 2°C scenario 2024*).



*Source: POLES-JRC 2024*

**Manufacturing costs**

The IEA estimates heat pump manufacturing to cost around EUR 180-225 per kW in Europe and the United States today, which is around twice the estimate for China. Manufacturing is assessed in this analysis at the final assembly step, so components (e.g. compressors) and their materials make up the bulk of manufacturing costs (IEA, 2024).

The components accounting for significant portions of the total cost of an air-water heat pump are the compressor (30%), controls (20%), heat exchangers (17%), housing (13%), valves (9%), fan (5%), pump (2%), pipework (2%) and refrigerant (2%) (Nesta 2022). For industrial heat pumps, the shares would likely be similar but without the housing. When it comes to material costs, the IEA estimates that the highest cost is for copper, accounting for more than 50% of the total costs for materials, followed by steel (around 20%), aluminium (around 15%) and nickel (around 10%) (IEA, 2024).

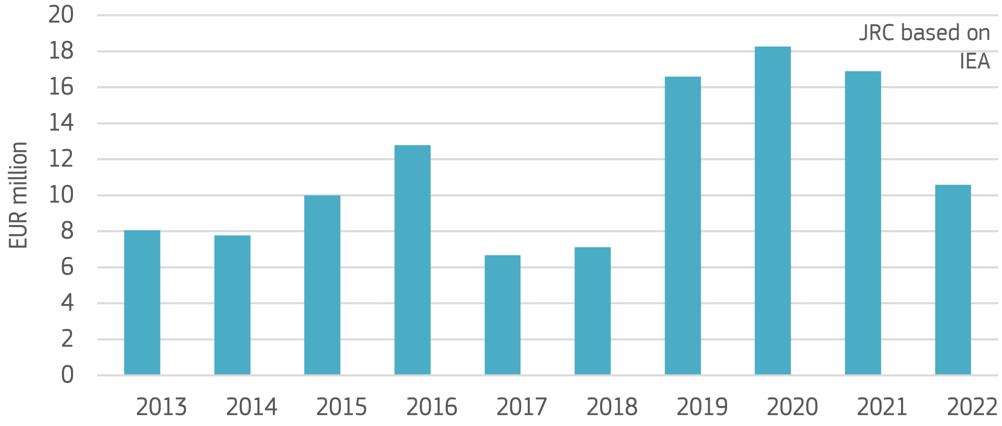
## 2.4 Public research funding

Public RD&I investment is analysed based on an IEA-curated dataset that includes data from Member States and other OECD countries. EU funding from the Horizon 2020 (H2020) and Horizon Europe Framework Programmes have been included since 2014. Section 2.8 also provides an overview of H2020, the framework for heat pumps set out in the SET-Plan working groups on “energy efficiency in buildings” and “sustainable and efficient use of energy in industry”, and other initiatives.

Since 2013, Member States have spent about EUR 118 million on public RD&I into heat pumps (the code also includes chillers). The highest public RD&I investment in Member States occurred between 2019 and 2021, at around EUR 16-18 million (Figure 17). From 2013 to 2023, the highest share of spending in EU public RD&I investment was in Austria (31%), followed by Denmark (27%), France (19%) and the Netherlands (13%); data for Germany is only available for 2019 (Figure 18).

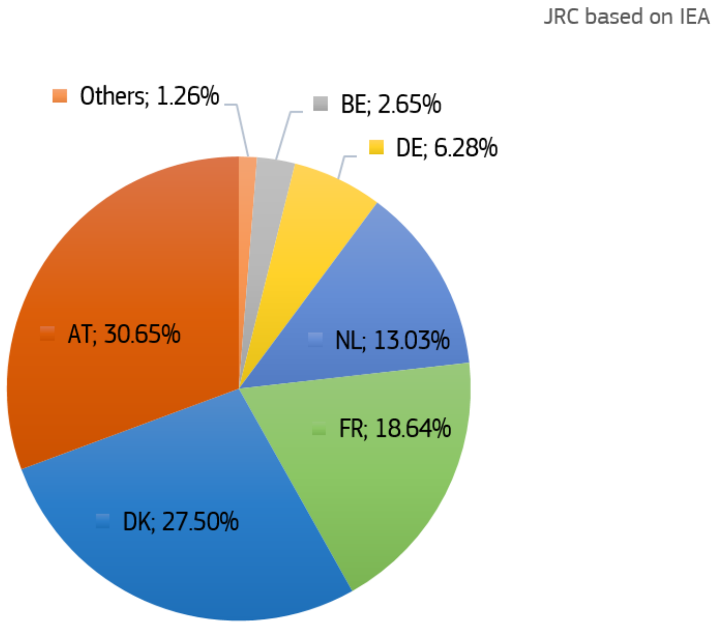
Over the same period, OECD countries spent around EUR 320 million (IEA 2024). From 2013 to 2022, the largest share of spending was by Japan (49%), followed by the EU (36%), China (8%), Norway (3.4%) and Canada (3.2%).

**Figure 17:** Public research investments in heat pumps in the EU



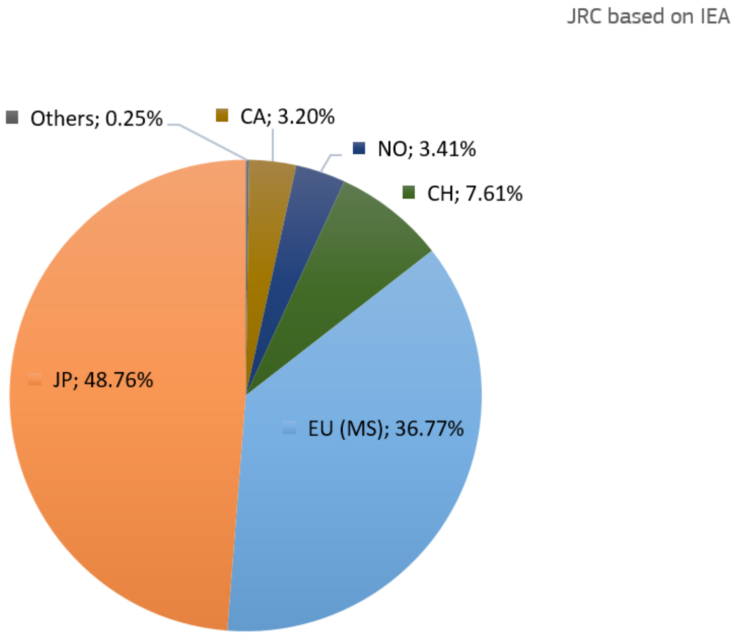
*Source: JRC based on (IEA 2024)*

**Figure 18:** Share of public research investment in heat pumps by Member State



*Source: JRC based on (IEA 2024).*

***Figure 19:*** *Share of public research investment by OECD member countries*

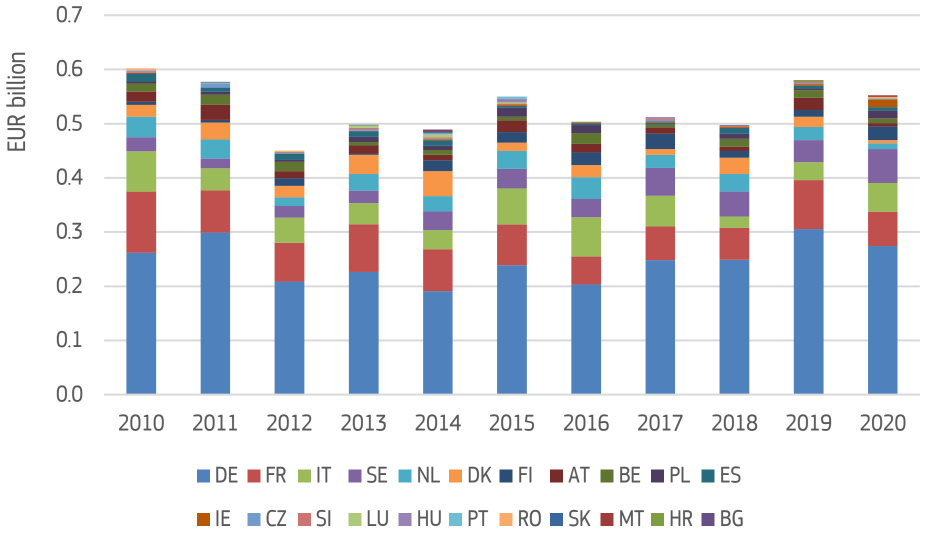


*Source: JRC based on (IEA 2024).*

## 2.5 Private research funding

Data on private RD&I investments are available for the entire HVAC (Heating, Ventilation, and Air Conditioning) sector. The estimate of the share of heat pumps in total HVAC private RD&I investment is based on patenting data and accounts for approximately 13% in the EU. Among EU countries, Germany leads in investment volume, followed by France, Italy and Sweden (Figure 20). Internationally, in 2020, China led in the private RD&I investment, followed by Europe, Japan, and the United States. The top EU investors in HVAC from 2015 onwards were Robert Bosch (Germany), followed by Miele (Germany), Bosch Siemens Hausgeräte (Germany), and E.ON Sverige (Sweden).

**Figure 20**: Private investments in research and innovation in the HVAC sector per Member State



*Source: JRC based on PATSTAT data.*

**The importance of research and development for industrial applications**

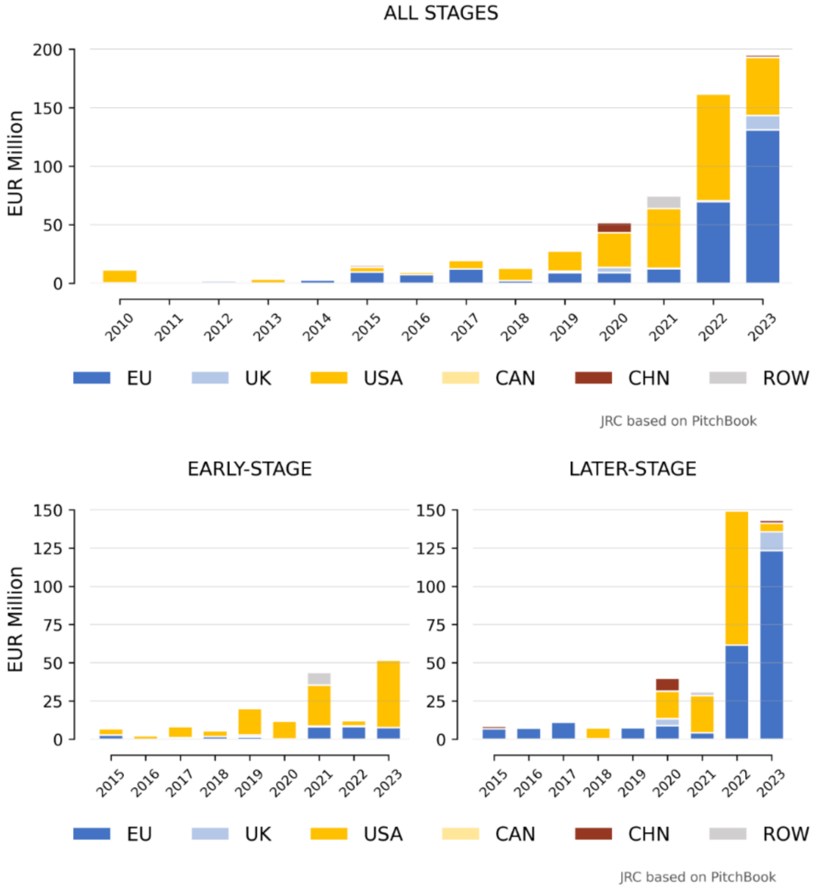
To realise the significant potential of applying industrial heat pump technologies, RD&I projects are needed to bring them to market as fast as possible. It is crucial that RD&I projects extensively involve industrial partners to facilitate the rapid scaling up and commercialisation of the developed technologies. Additionally, these developments must be implemented on a large scale to build confidence and create momentum.

While some process industries, such as food and beverage, are already relatively open to industrial heat pumps, there are still massive industries that are not yet targeted by projects to a sufficient extent, such as minerals (bricks, roof tiles, gypsum, asphalt). In terms of innovation, the key focus areas are temperature lift, efficiency improvement, flexible operation, and the increased use of natural refrigerants.

### Venture capital and early and later-stage investments

Worldwide, venture capital investments and corporate investments at all stages (early and late)[28] increased significantly in 2022 (from EUR 70 million to EUR 155 million) and continued growing in 2023, reaching almost EUR 200 million (Figure 21), in current prices (2024). Investments in these innovating companies grew significantly in the EU, by almost 50% in 2023.[29] From hosting 41% of all innovating companies in 2022, their share reached almost 80% in 2023 in the EU. The United States had a significant increase in 2022 but a slowdown in 2023.

**Figure 21:** Global VC/PE investment, by region for all deals (top), early-stage deals (bottom left) and later-stage deals (bottom right)



*Source: JRC based on PitchBook*[30].

Early-stage investment dropped in 2022 and increased again in 2023 (Figure 22). The increase in 2023 is mainly due to the limited activity in 2022 and the emergence of start-ups on the verge of reaching the scale-up stage. The United States was the leading market for early-stage investments (hosting 90% of all early-stage investments in 2023). For later-stage investments, the EU had significant growth, from EUR 5 million in

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[28] The early stages indicator include Pre-Seed, Accelerator/Incubator, Angel, Seed and Early stage VC investments; it also include public grants. The later stages indicator reflect growth investments for the scale-up of start-ups or larger SMEs. It include Late Stage VC, Small M&A and Private Equity Growth/Expansion

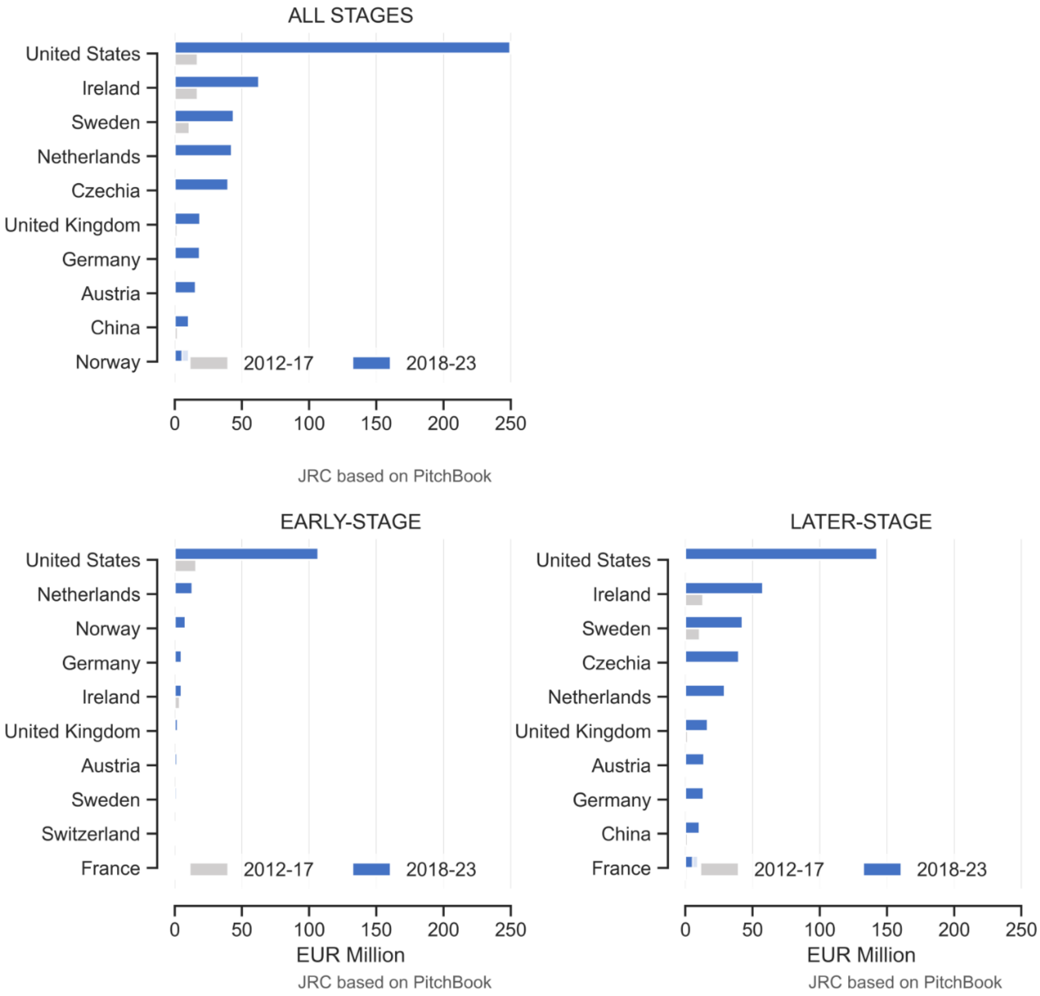
[29] The lists of companies include two distinct populations: VC and corporate companies. Corporate companies have a relevant patenting activity among the subsidiaries of top RD&I investors from the EU Industrial R&D investment Scoreboard. VC companies are selected based on their activity description and this selection does not rely on patents. This selection tries to focus on companies that develop and manufacture technological solutions as much as possible.

[30] Private Equity (PE) refers to capital investments (ownership or interest) made into companies that are not publicly traded. Venture capital (VC) is a form of private equity and a type of financing that investors provide to start-up companies and small businesses that have long-term growth potential

2021 to EUR 125 million in 2023. With this, the EU is in a lead position for later-stage investments worldwide, accounting for 95% of investment in 2023.

Between 2018 and 2023, the United States led early-stage investment, followed by the Netherlands, Norway and Germany. By contrast, the EU as a whole is doing better in the later stage, with the United States still in the lead followed by Ireland, Sweden, Czech Republic and the Netherlands. Examples of EU companies receiving venture capital investments include Exergyn (IE), Heat transformers (NL), Easyserv (SE) and Teccontrol (FR).

**Figure 22:** VC/PE investment in top 10 beneficiary countries, by period for all deals (top), early-stage deals (bottom left) and later-stage deals (bottom right)

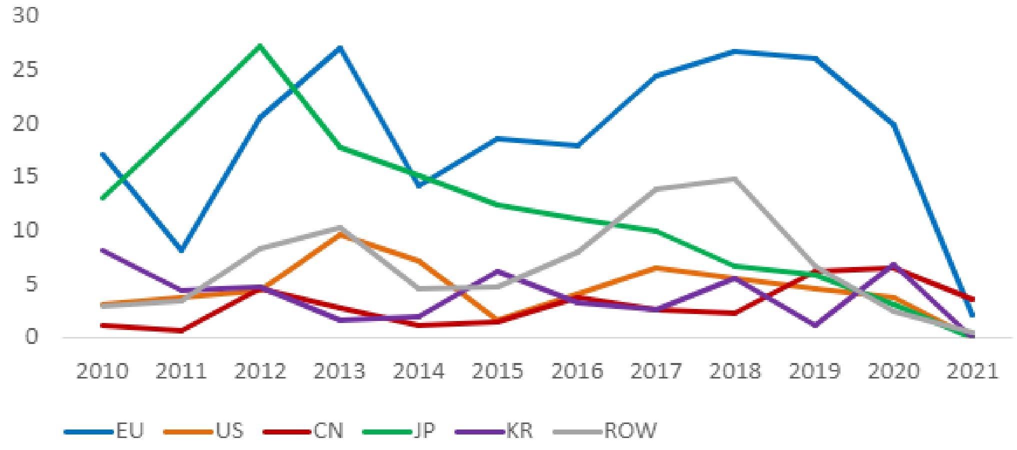


*Source: JRC based on PitchBook*

## 2.6 Patenting trends

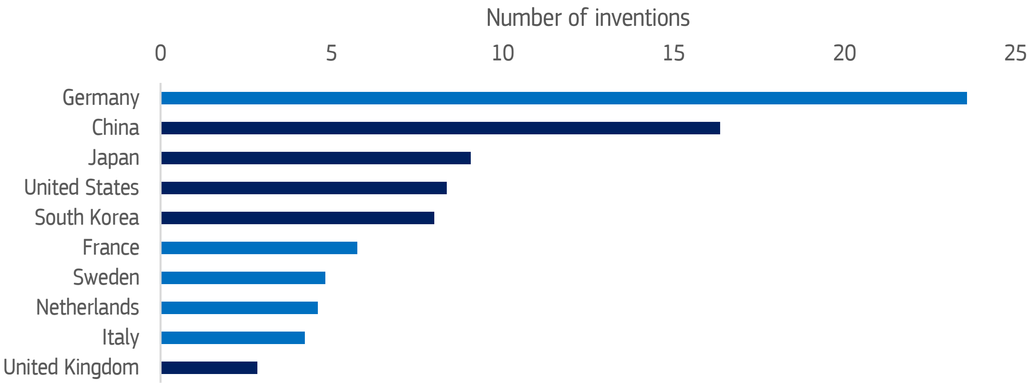
High-level patenting inventions in the EU grew between 2016 and 2019 but slowed down in 2020 and 2021 (Figure 23).[31,32] The EU was a leader in high-level patenting until 2020, but by 2021, China had slightly surpassed it.[33] At the country level between 2019 and 2021, Germany led in high-level patenting activities, followed by China, Japan and United States (Figure 24). Among EU countries, France, Sweden, the Netherlands, and Italy, all featured among the global top 10.

**Figure 23:** Number of high-value inventions for the major economies



*Source: JRC based on EPO PATSTAT 2023.*

**Figure 24:** Top ten countries for high-value inventions, 2019-2021



*Source: JRC based on EPO PATSTAT 2023.*

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[31] Patenting inventions measure the inventive activity. High-value inventions refer to patent families that include patent applications filed in more than one patent office.

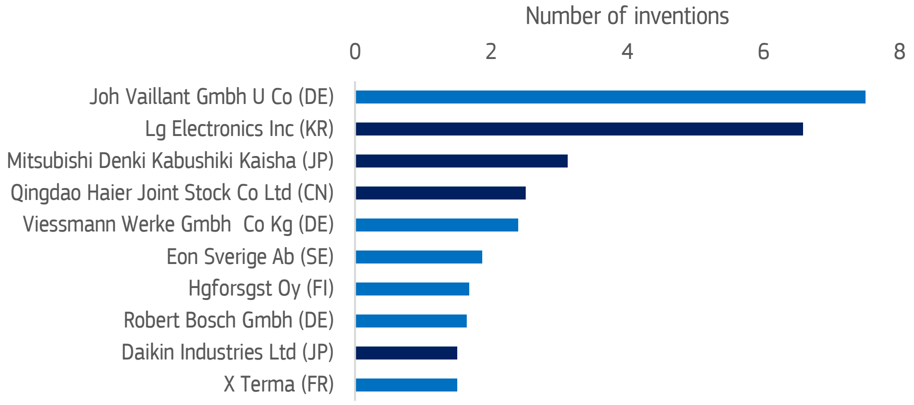
[32] Patent code Y02B refers to climate change mitigation technologies related to buildings. This level is further disaggregated into Geothermal heat pumps, Hot water central heating systems using heat pumps, Hot air central heating systems using heat pumps, Heat recovery pumps, i.e. heat pump based systems or units able to transfer the thermal energy from one area of the premises or part of the facilities to a different one, improving the overall efficiency.

[33] The data for 2021 is incomplete.

Among the companies, Vaillant (Germany) and LG (Korea) led high-value patenting activities (Figure 25), followed by Mitsubishi (Japan) and Quingdao (China).[34] With five companies among the world top 10, the EU is well represented in high-value patenting activity. Some examples of patent activities:[35]

- Vaillant: Safety Device for a heat pump outdoor unit (EP3767186A1);
- LG: Water-heater tank for heat pump system and method of controlling (CN113494786A), integrated heating and cooling device (KR20210046302A);
- Mitsubishi: Geothermal heat pump system and control method for geothermal heat pump system (WO2019082267A1), A heat source system (DE112017006742T5);
- E.ON Sverige: District energy distributing system (PL3622224T3).

**Figure 25:** Top 10 companies for high-value inventions, 2019-2021



*Source: JRC based on EPO PATSTAT 2023.*

Of all patenting activities, the EU was the leader in high-value inventions (59%), followed by the United States and the rest of the world. China was the leader in total number of patenting activities[36] but the share of high-value inventions made up only 3% and international activities only 1% between 2019 and 2021.[37]

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[34] The location of companies is defined based on their headquarters.

[35] https://worldwide.espacenet.com/.

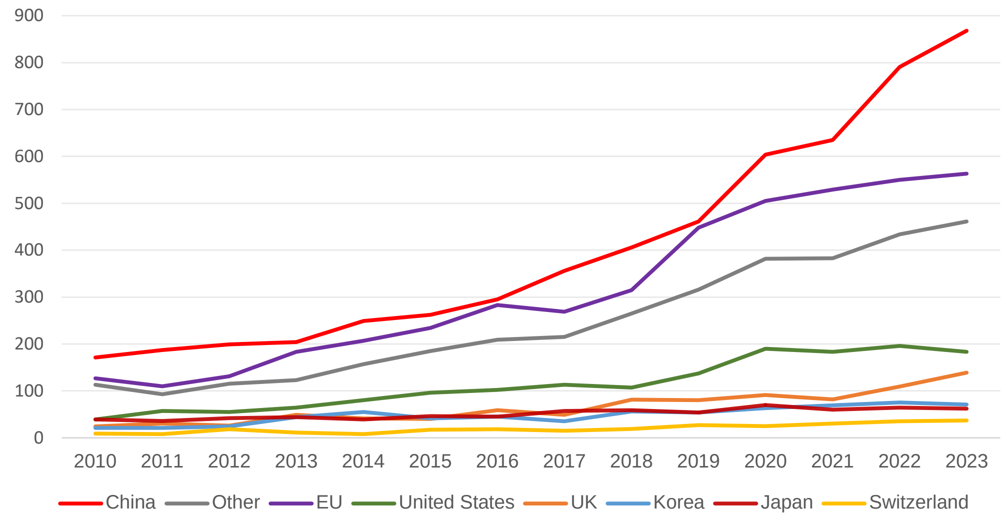
[36] The total number of inventions refers to all applications and does not exclude those that are not accepted. Moreover, many of the applications are likely within Chinese territory.

[37] International activities refer to patents in different regions.

## 2.7 Bibliometric trends and level of scientific publications

This section builds on JRC TIM (Tools for Innovation Monitoring) data on publications.[38] In terms of number of peer-reviewed articles, China started to pull ahead of the EU and the United States in 2020 and now has a clear lead (Figure 26). By h-index, however,[39] the EU, with 123 is ahead of China on 101 and the United States on 79.

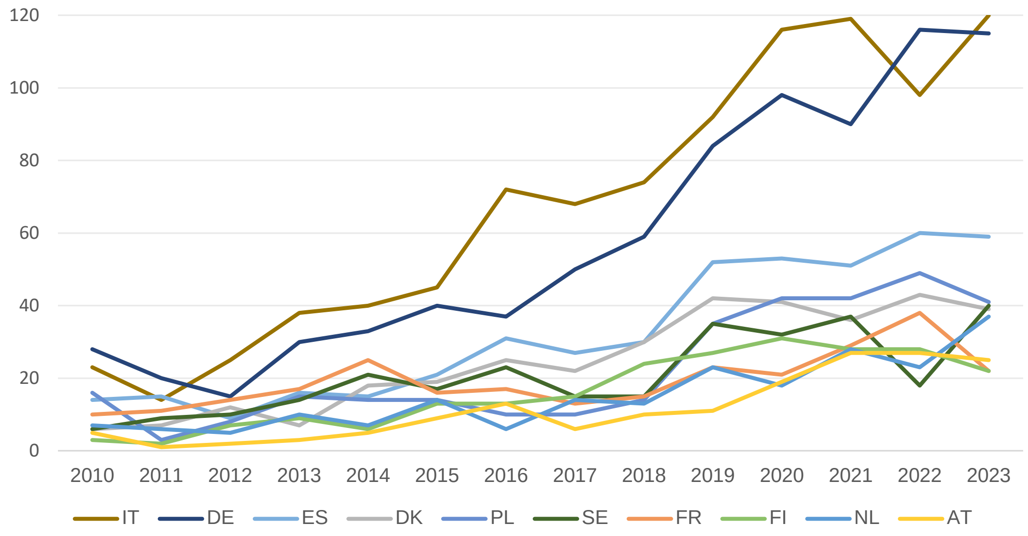
**Figure 26:** Number of peer-reviewed articles on heat pumps by country, 2010-2023



*Source: Based on JRC TIM.*

Within the EU, Italy and Germany publish the most articles, with Spain and Poland becoming more prolific in recent years, and Denmark maintaining its longstanding expertise. 27 shows the top ten Member States by publications over the period.

**Figure 27:** Number of peer-reviewed articles on heat pumps by Member State, 2010-2023



*Source: Based on JRC TIM.*

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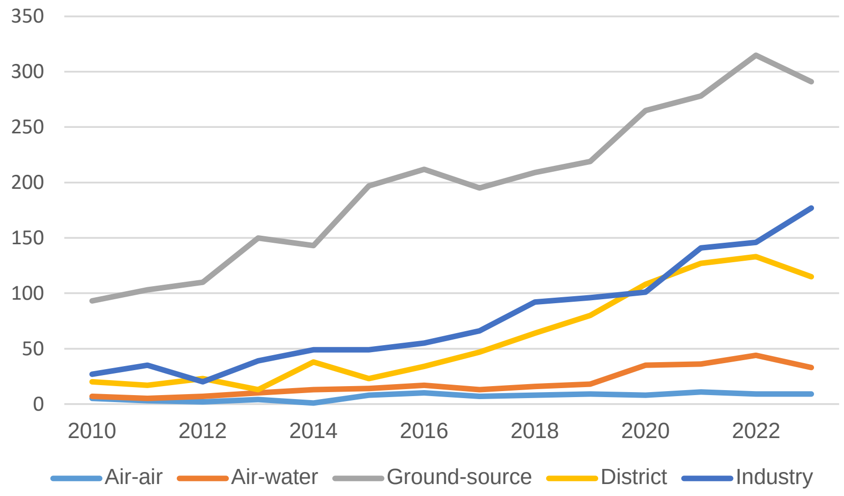
[38] See also the 2022 edition of this report for a similar analysis using a different breakdown of heat pump types.

[39] The h-index is the largest number h such that at least h articles for that topic were cited at least h times each.

Categorising articles by heat pump type or application is not a straightforward task, yet it unveils some interesting trends, visible in Figure 28. Notably, ground-source heat pumps have garnered significantly more attention in the academic literature, with a higher volume of research papers dedicated to this technology compared to air-air and air-water heat pumps. This disparity in research attention may be attributed to the presence of intriguing research questions specific to ground-source heat pumps, such as cost reduction strategies and drilling optimization techniques. Alternatively, the larger market share and commercial dominance of air-air and air-water heat pumps may have led to a greater proportion of research and development (R&D) activities being conducted in-house by corporate entities, with fewer studies being published in academic outlets. Second, there is a clear upward trend of research papers focusing on industrial heat pump applications.

**Figure 28:** Number of peer-reviewed articles on heat pumps by type and application, 2010-2023



*Source: Based on JRC TIM.*

## 2.8 Impact and trends of EU-supported research

EU support for public RD&I into heat pumps is provided mainly through the Horizon Europe research and innovation programme for 2021-2027, the LIFE programme and the Innovation Fund.[40] Combining Horizon Europe and its predecessors, 59 ongoing and completed projects worth around EUR 350 million have been dedicated to heat pumps (CINEA, 2023). Those projects span design, manufacturing, installation, operation and other areas such as disposal, business models, and skills.

EU funding instruments provide support from low-TRL breakthrough technology and materials development, to the development of components and systems, to their demonstration in laboratories and in the field, and finally to deployment, including skills development. Projects that started in the period 2014-2022 were supported with a total of EUR 277 million, mainly for the integration of heat pumps in buildings (54%) and in DHC networks (29%), and for the development of heat pumps and related materials (17%). Projects often treat heat pumps as sources of electricity demand or as part of larger systems rather than focusing on the heat pump technology itself. Several projects focus on industrial applications.

An example of a project funded by the EU's LIFE programme is the HEATLEAP project.[41] This project aims to demonstrate the environmental and economic benefits of waste heat recovery systems such as large heat pumps in energy-intensive industries and gas expanders in gas distribution networks by testing these technologies at real scale.

At EU level, the framework for technology development is set by the implementation plans of the SET-Plan working group on “energy efficiency in buildings”, the SET Plan working group on “sustainable and efficient use of energy in industry” and the Strategic Research and Innovation Agenda of the European Technology and

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[40] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls_en
[41] https://heatleap-project.eu/

Innovation Platform on Renewable Heating and Cooling (RHC Platform). The SET-Plan working group on energy efficiency in buildings has specific targets for heat pumps for building applications:

- Reduce costs for small and large heat pumps by 50% (compared to the 2015 market price);
- Develop prefabricated, fully integrated "plug and play" hybrid/multisource heat pump systems and integrated compact heating/cooling plants based on modular heat pumps.[42]

The SET-Plan working group on sustainable and efficient use of energy in industry has specific targets for industrial heat pumps:[43]

- Develop and demonstrate heat pump solutions (to TRL 7 for temperature up to 200/250°C and to TRL 6 for temperature above 250°C) by 2025;
- Develop and demonstrate heat pump systems to TRL 8 by 2030, increasing efficiency by 5% compared to the 2025 level, reduce LCoE (levelised cost of energy) by 10% compared to the 2025 level.

The European RHC[44] (Technology and Innovation platform on Renewable Heating and Cooling) identified the priority topics for the renewable heating and cooling sector to be considered for the drafting process of the Horizon Europe Work Programme 2025. The priority topics for heat pumps, according to RHC-ETIP's Horizon Working group, might include (RHC 2024):

- Heat pump value chain efficiencies;
- Innovative components and configurations for heat pumps;
- Heat pumps – industrial synergies;
- Enabling flexible heat pumps to support the grid and integrating the energy systems.

Several Member States are also members of the IEA TCP on Heat Pumping Technologies.[45] Its research areas (Annexes) currently include:

- Heat pumps in residential multi-family buildings in cities;
- Advanced cooling and refrigeration technology development;
- Heat pump systems with low GWP refrigerants;
- Internet of Things for heat pumps;
- Heat pumps in multi-vector energy systems;
- High-temperature heat pumps;
- Placement impact on heat pump acoustics;
- Safety measures on flammable refrigerants.

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[42] See https://setis.ec.europa.eu/implementing-actions/energy-efficiency-buildings_en.

[43] https://setis.ec.europa.eu/implementing-actions/sustainable-and-efficient-energy-use-industry_en.

[44] www.rhc-platform.org.

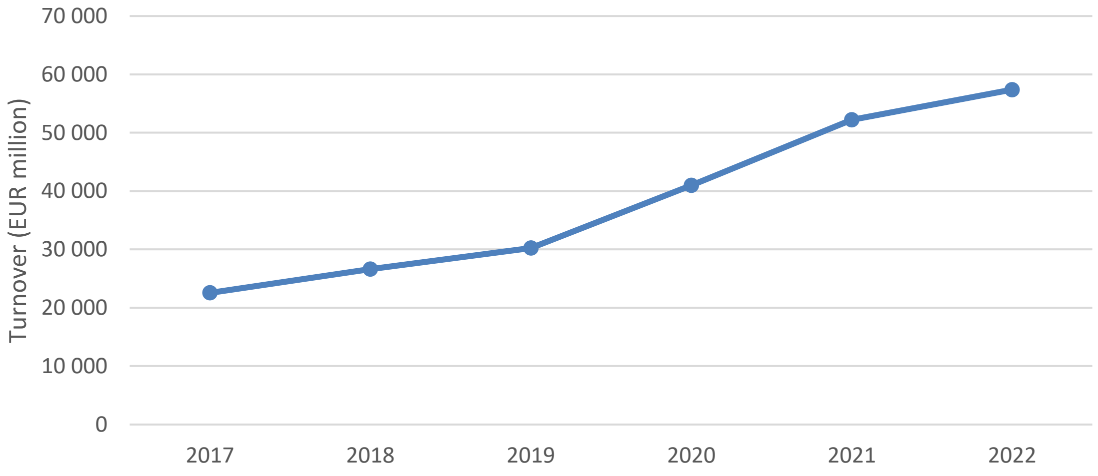
[45] Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands and Sweden.

# 3 Value chain analysis

## 3.1 Turnover

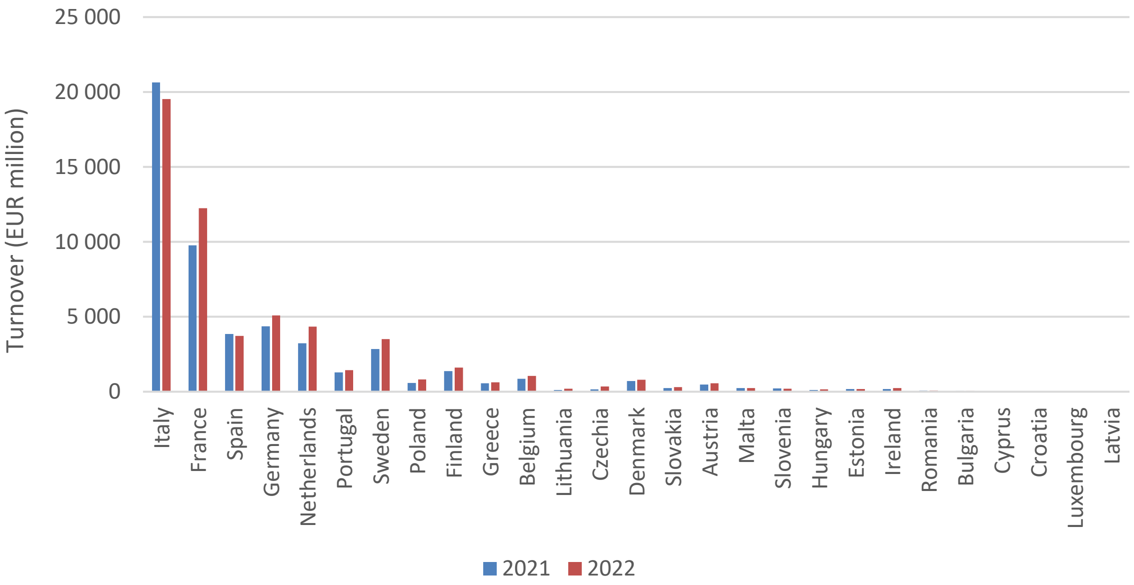
According to EurObserv'ER, from 2017 to 2022, the EU heat pump sector experienced a steady increase in turnover, rising from almost EUR 23 billion in 2017 to EUR 57 billion in 2022 (Figure 29). In 2022, Italy had the highest turnover, nearly EUR 20 billion, followed by France (almost EUR 12 billion) and Germany (EUR 5 billion). Most Member States experienced an increase in turnover in 2022, except for Italy, Spain and Slovenia, which saw a slowdown of -5%, -4% and -9% respectively. Turnover in other countries increased in 2022, with the highest increase in the Czech Republic (119%), followed by Lithuania (82%), Poland (41%) and Ireland (41%). EurObserv'ER takes into account investment in new installations, operation and maintenance of existing heat pumps, including newly added heat pumps, and production and trade of equipment.

**Figure 29:** Turnover of the EU heat pump sector between 2017-2022.



*Source: JRC based on (EurObserverER 2023), (EurObserverER 2021), (EurObserverER 2019).*

**Figure 30:** Turnover of the heat pump sector in EU Member States in 2021 and 2022



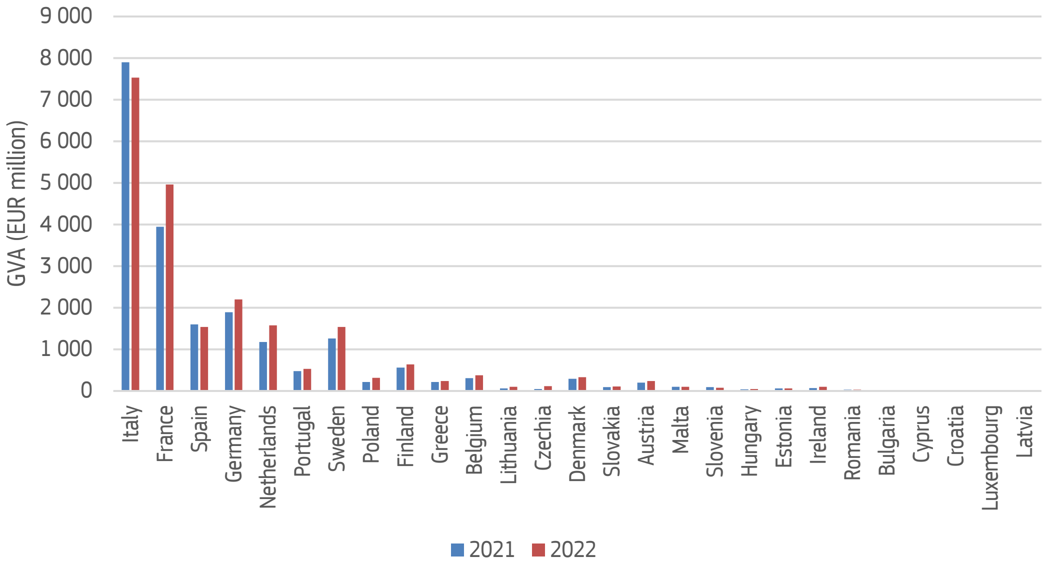
*Source: (EurObserverER 2023)*

*Note: The values for Cyprus, Croatia, Luxembourg, and Latvia are <10 EUR million.*

## 3.2 Gross value added

Direct GVA values in the EU calculated by EurObserv'ER were 22.8 billion in 2022, which was a 10% annual increase. With about EUR 7.5 billion, Italy leads in direct GVA, followed by France (almost EUR 5 billion), Spain (EUR 1.5 billion) and Germany (EUR 2.2 billion).

**Figure 31:** Direct Gross Value Added (GVA) of the EU heat pump sector in 2021 and 2022.



*Source: JRC based on (EurObservER 2023)*

*Note: The values for Cyprus, Croatia, Luxembourg, and Latvia are <10 EUR million.*

## 3.3 Environmental and socioeconomic sustainability

The JRC proposal for a sustainability framework for energy technologies includes three dimensions: supply security, environmental sustainability, and social sustainability (Mancini, et al. 2023). Energy security encompasses economic aspects, such as stable energy supply, accessibility of resources, and trade considerations. Environmental sustainability is based on the Product Environmental Footprint methodology and aligned with the SSbD (Safe and Sustainable by design) framework. The social sustainability dimensions consider impacts on workers, local communities, value chain actors and society, according to the Social Life Cycle Assessment methodology. The list of indicators for each dimension and related information on heat pumps is included in the Annex.

According to a recent study (European Commission 2024), the main criticalities for energy security related to heat pumps in the segments of the value chain were identified as follows: critical raw materials (CRMs), physical vulnerability, and skills. Physical vulnerability is related to physical disruptions of the electricity grid, as large amounts of renewable electricity are needed to deploy heat pumps.

When it comes to CRMs, copper, aluminium and nickel are essential, as they are also used in many other clean energy technologies' value chains. In addition to these CRMs, semiconductor chips are also essential for operating heat pumps. Recent events have shown the vulnerability of supply chain disruptions.

We compiled life-cycle assessment (LCA) information for heat pumps from the PEP ecopassport[46] database, which provides $CO_2$ emissions estimates for various stages of the heat pump value chain, including manufacturing, use, and end-of-life, as well as electricity consumption throughout the life cycle. By combining these data points, we calculated the ratio of $CO_2$ emissions per kWh of electricity consumed over the entire life cycle. To express the results in terms of $CO_2$ per kWh of heat delivered, we utilised the Seasonal Coefficient of Performance (SCOP) values declared by manufacturers to convert electricity consumption into thermal energy output. Our analysis resulted in an estimated average $CO_2$ emission value of 0.11 kg $CO_2$/kWh over the life time, as an average across all typical heat pump models considered.

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[46] https://register.pep-ecopassport.org/

The shortage of skilled workers is currently a bottleneck in deploying heat pumps in both domestic and industrial applications. Especially for industrial heat pumps, the design often needs to be customised to the specific criteria of the end user. While the basic training for heat pump installation is relatively quick, there is strong competition for workers across clean energy technologies.

Another critical factor is affordability. While in domestic applications, heat pumps are often cheaper than a gas boiler, in industrial applications – especially in high-temperature ranges – industrial heat pumps are not yet competitive in costs with existing fossil fuel-based heating solutions. However, cost decreases are expected over time due to current research and innovation efforts, as well as political and economic incentives to decarbonise industrial processes.

## 3.4 Role of EU companies

Heat pump manufacturers mostly serve their local markets, with only China exporting significant numbers of heat pumps (IEA 2023). Assembly of the heat pump unit tends to be concentrated relatively close to the point of sale or installation. The location of manufacturing is important for logistics.

EU manufacturers are mainly assemblers, though some assemblers produce some components as well, and there are a few dedicated component manufacturers. Apart from serving the country in which their heat pumps are produced, manufacturers tend to export their products to neighbouring countries (Figure 43 in section 4.2).

Between 60% and 73% of heat pumps installed in Europe are produced in Europe. According to EHI, more than 80% of its members assemble their heat pumps fully in the EU, but the situation appears more fragmented for components. The main components come from suppliers outside the EU. Specialised components, such as compressors and refrigerants, are produced by a small selection of manufacturers (some EU heat pump manufacturers will make these in-house).

Specialised components are not always unique to the heat pump supply chain. However, some specific compressors, such as scroll compressors, are specifically manufactured for heat pumps. Less specialised components such as fans, pumps, conventional controls and pipework are produced globally and at scale. However, some components are partly produced in Europe, including pumps, fans, heat exchangers and electric motors. Vessels (buffer tanks) are, for example, 100% manufactured in Europe.

The EU has a world-leading role in industrial heat pumps. Key suppliers are located in Europe, covering the entire value chain with all relevant components. However, this value chain needs massive investments to sustain its leading role and extend production capacity globally, since the USA and Asia are already investing in scaling up their supply chains, trying to catch up with the EU suppliers and entering the EU market.

There are approximately 255 heat pump facilities across 21 Member States based on JRC analysis using data from EHPA and other sources. The largest number of these companies is in Italy, with Germany, Poland, France and the Netherlands following closely behind. The majority of the facilities are manufacturers of heat pumps for the residential and services sectors, while other segments are less well represented, such as component manufacturers and large and industrial heat pump facilities.

The top ten companies with the greatest number of locations in the EU are:

1. Daikin (Japan), with subsidiaries in eight countries: Belgium, Czech Republic, France, Germany, Italy, Netherlands, Poland, and Spain.
2. Bosch (Germany), with subsidiaries in six countries: Czech Republic, France, Germany, Poland, Portugal, and Sweden.
3. Viessmann (USA), with subsidiaries in five countries: Austria, France, Germany, Poland, and Switzerland.
4. Vaillant (Germany), with subsidiaries in four countries: Austria, France, Germany, and Slovenia.
5. Nibe (Sweden), with subsidiaries in four countries: Czech Republic, France, Germany, and Sweden.
6. BDR Thermea (Netherlands), with subsidiaries in four countries: France, Italy, Netherlands, and Spain.
7. Stiebel Eltron (Germany), with subsidiaries in four countries: Austria, Germany, Slovenia, and Sweden.
8. Mitsubishi Electric (Japan), with subsidiaries in four countries: Germany, Italy, Netherlands, and the United Kingdom.

9. Panasonic (Japan), with subsidiaries in three countries: Czech Republic, Germany, and Spain.
10. Atlantic (France), with subsidiaries in four countries: Austria, Belgium, France, and Slovenia.

**Figure 32:** Manufacturing facilities of heat pumps in Europe, 2022

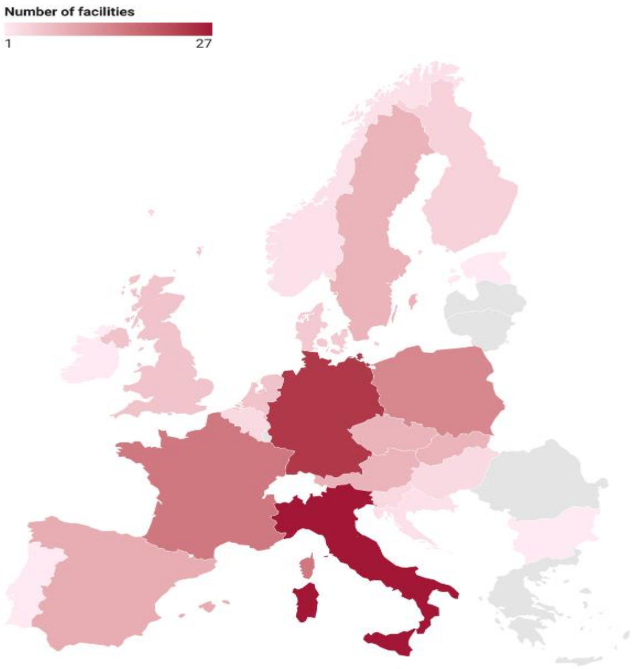
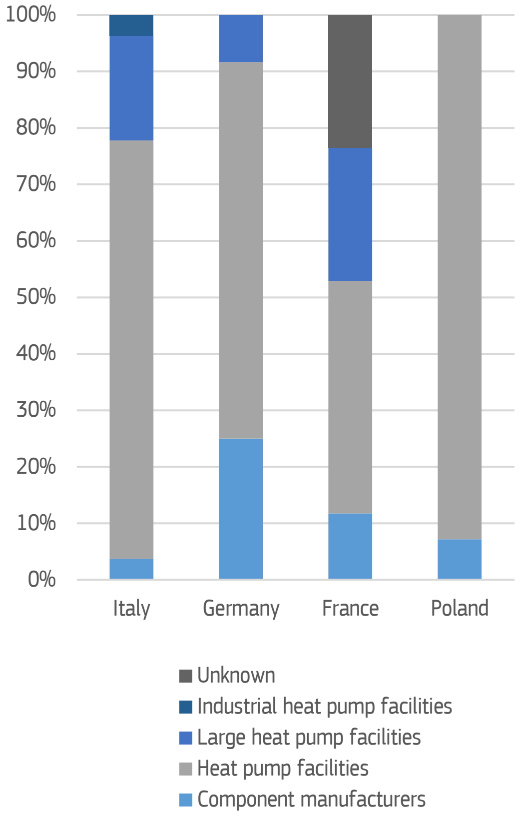


**Figure 33:** Manufacturer facilities by the type of production



*Source: (Bruegel 2024) based on EHPA and IEA (Figure 32 and 33).*

Many manufacturers serve the local market because heat pumps are bulky and inefficient to transport long distances, making local manufacturers more attractive. Moreover, heat pump models are often specific to their end-markets because of historical practice, adaptation to regional conditions and compliance with local regulations. Manufacturers offer a wide variety of models. For example, the Top Ten database showcasing the most energy-efficient products provides a list of 273 different models of brine-to-water heat pumps, water-to-water heat pumps and air-to-water heat pumps for single-family homes and apartment buildings.[47] Other parameters that vary from one model to another include the refrigeration process, compressor series, evaporator design, software version of the controller, and more.

Heat pumps for large (commercial or apartment) buildings are provided in the EU by Aermec, Dalmajica Klima, Frost, Inno+, Johnson Controls Hitachi, SmartHeat and others. EU companies active in the DHC segment include Cetetherm (controls), Danfoss (components and software), Engie, Fenagy, MAN Energy Solutions, Mayekawa, Metro Therm, Ochsner, Sabroe, Siemens Energy (a spin-off of Siemens with activities across fossil and renewable sectors), Turboden (Mitsubishi Heavy Industries), Vattenfall and Wien Energy. In almost all cases, heat pumps are only part of these companies' activity.

In industrial heat pumps, the EU plays a leading role at the world level. Key suppliers are located in Europe, covering the entire value chain with all relevant components. There are 36 manufacturers of commercially

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[47] www.topten.eu/private/products/heat_pumps.

available large-scale heat pumps for heating capacities above 0.5 MW (Agora Energiewende 2023). Below 1 MW, most heat pumps are already highly standardised products. Above 10 MW, heat pumps become highly customised products, frequently supplied through large EPC (Engineering, Procurement and Construction) contracts (Agora Energiewende 2023). In the industrial heat pump market, European companies include Aermec, ECOP, Enertime, Engie, Equans, Fenagy, Frost, Galletti, GEA, HiRef, Inno+, Keyter, MAN, Mayekawa, MTA, NRGTeq, Ochsner, Piller, Qpinch, Rank, Sabroe, Samifi, Siemens Energy, SmartHeat, Spilling, SRM, Sustainable Process Heat, Templari, ThermoNova, Turboden, Waterkotte, Weel & Sandvig, Winterwarm and X-Terma.

Testing or research centres include, among others, Fraunhofer, TUV SUD, HLK Stuttgart and TU Aachen (Germany), CETIAT and Paris Mines (France), KIWA and TNO (Netherlands), Austrian Institute of Technology (Austria), Polimi (Italy), Danish Technological Institute (Denmark), and KTH Stockholm (Sweden). The main manufacturers also have their own research centres. In industrial heat pumps, prominent research organisations in the EU include TNO and the University of Lyon (France).

Heat pumps are represented by a number of associations both at the national and EU levels. Some of the main associations at the EU level are the European Heat Pump Association, Euroheat & Power, the European Heating Industry, the European Geothermal Energy Council, ATMOsphere and The European Partnership for Energy and the Environment. There are also several associations representing refrigeration and air conditioning sectors, as well as components. BEUC (The European Consumer Organisation) represents consumers, and there are several environmental NGOs active in the segment too, such as the the European Environmental Bureau.

Component manufacturing is a truly global operation. The components accounting for significant portions of the total value of an air-source electric heat pump are the compressor (~25%), controller (~25%), heat exchangers (~15%), housing (~13%), valves (~10%), fan (~5%), pipework (~2%) and refrigerant (~2%) (Eunomia, 2020).

**Compressor** design and manufacturing is a specialised activity, so it has become dominated by a small number of global suppliers. More than 90% of compressors in European heat pumps are imported, according to industry associations. EU imported slightly more compressors than we exported. 52% of EU compressor imports were from countries outside the EU (i.e. 48% from another Member State). Most imports came from China, Japan and the United States. At the same time, 43% of compressors manufactured in the EU are exported to countries outside the EU, the largest importers being the United States, China and Turkey. European players include Danfoss (Denmark), Bitzer (Germany), Tecumseh (France) and Copeland compressors (Belgium), Dorin (Italy). Some larger Asian electronics companies manufacture their own compressors, such as Hitachi and Daikin in Japan. Mitsubishi Electric manufactures compressors in Thailand. Most materials used in constructing compressors, such as steel, aluminium, copper, and various plastics and rubbers, can be produced within the EU. Certain specialised materials might have to be imported.

**Refrigerant** supply is dominated by China (e.g. Dongyue and Sinochem), with the United States (Chemours (with a subsidiary in Switzerland), DowDuPont and Honeywell) in second place. Other major international players are Asahi Glass (Japan) and Daikin (Japan); SRF (India); and Koura (Mexico). EU suppliers are Arkema (France) and the Linde Group (Germany). The raw material used to manufacture fluorinated gases (F-gases), fluorspar, is listed as a critical raw material. China provides around 65% of the global market of Fluorspar. 25% of the fluorspar used in the EU is sourced from Mexico. EU has a small amount of domestic production and is reliant on imports. Natural refrigerants and especially R290 (propane) are already on the market.

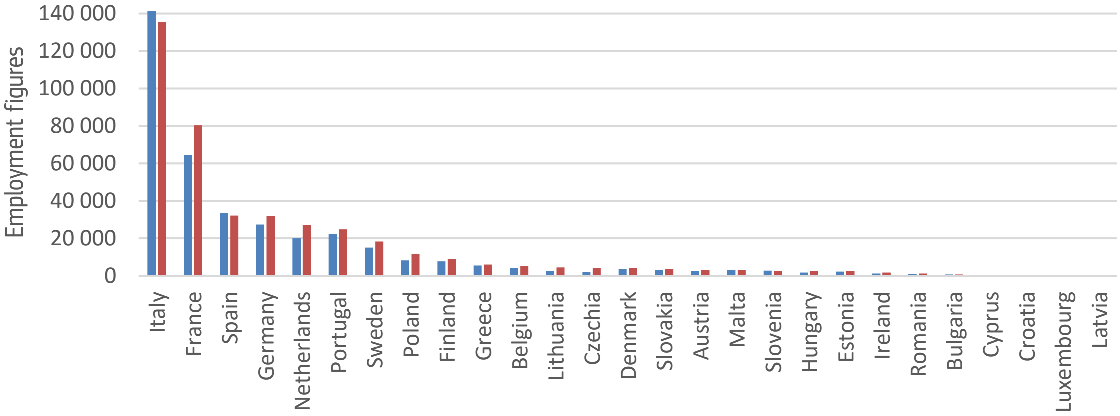
**Heat exchangers, housing and controllers** are less specialised and are also used in other products. They are distributed among a wider range of companies worldwide. However, European companies Danfoss (Denmark), CAREL (Italy), Alfa Laval (Sweden) and SWEP (Sweden) are leading in many components.

**Fans** are used in many products, including clean energy technologies such as electric vehicle charging and battery storage. They are mainly manufactured by Ziehl-Abegg and ebm-papst (Germany), specifically for the pumps market by Wilo (Germany) and Grundfos (Denmark).

## 3.5 Employment

The heat pump sector provides jobs to more people than any other renewable energy technology in the EU, employing 416 200 people in 2022 (EurObservER 2023).[48] The employment growth was more than 10% that year. The biggest countries by employment were Italy (135 400), France (80 300), Spain (32 200), Germany (31 900) and the Netherlands (27 100).

**Figure 34:** Employment (direct and indirect jobs) in the heat pump sector in 2021 and 2022.



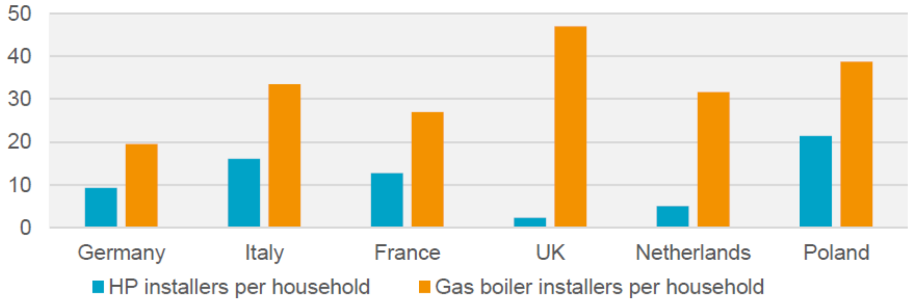
*Source: (EurObservER 2023)*

*Note: Employment expressed in full-time equivalents and covers direct and indirect jobs.*

The EU is currently experiencing a significant skills gap in its labour markets, particularly in the construction sector. The heat pump sector is no exception, and to achieve the REPowerEU installation targets by 2030, there is a pressing need for more skilled workers. According to the EHPA, the EU will require a minimum of 500 000 skilled employees by 2030, representing more than 200% growth. The European heat pump sector directly employed 170 000 people in 2023. Increasing manufacturing and installation capacity is a prerequisite for a faster heat pump rollout (EHPA 2024).

Employment in the heat pump sector encompasses roles in RD&I, manufacturing, installation (including drilling), and maintenance (including periodic checks). The EHPA market report for 2024 indicates that heat pump manufacturing accounts for the largest share of employment in the sector at 39.2%, followed by installation at 30.1%, component manufacturing at 19.6%, and service and maintenance at 11.1%. Currently, the challenge of installer capacity varies significantly across different countries in the heat pump sector. While countries like Spain, Italy and Poland do not currently face a shortage of installers with heat pump qualifications, the situation could change as heat pump sales accelerate (LCP Delta 2023).

**Figure 35:** Number of qualified heating installers per 10 000 households in four EU Member States and the UK



*Source: (LCP Delta 2023)*

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[48] Direct and indirect jobs. The number also covers heat pumps whose principal function is cooling, so especially the number for Italy, Spain and France is large due to this sector. Direct employment includes equipment manufacturing, engineering and management, operation and maintenance. Indirect employment refers to secondary activities, such as transport and other services.

Today, most installers are trained by manufacturers at their own training centres and programmes or by industry associations (ehi 2022). The training centres are located in the countries where they are present and where they are planning to expand their activities. They also collaborate with other key stakeholders, such as governments, industry associations and education institutions (Toleikyte, et al. 2023).

Installers generally offer a range of heating technologies, including boilers. Depending on the country and qualifications, they can also be known as heating engineers or technicians. They tend to be sole contractors or SMEs, which allows them to provide tailored expertise and personal service but can also be less efficient than larger structures. Significant time and expertise must be invested in dealing with customers, visiting properties, drawing up quotations, liaising with equipment and component manufacturers, and so on. Lead generation platforms aim to help with one part of this, connecting individual installers with prospective customers, with varying degrees of success.

There are also some larger installer firms and some specialised in heat pumps. thermondo (Germany) has more than 800 employees and is perhaps the largest installer in Europe. This scale enables new business models to develop, for example, thermondo offers rental rather than sale of the heat pump; the start-up Aira (Sweden) offers heat pumps on a monthly subscription in which customers pay nothing upfront and are instead charged a monthly fee that covers both installation and servicing. In 2022, rentals already accounted for 4% of total heat pump installations in Germany (LCP Delta 2023).

In 2023, the employment picture in the EU became less positive. Demand was not yet sufficient to fully utilise all the new production capacity that has been added, resulting in 3 000 jobs being cut or temporarily frozen in Belgium, Germany, France and Italy.

## 3.6 Energy intensity and labour productivity

### Energy intensity

Heat pumps provide space heating, cooling or DHW by using ambient heat and electricity that drives the compressor and heat exchanger. The electricity consumption of a heat pump depends on various factors, including the climate, the size of the heated area and the efficiency of the house.

Typically, a heat pump can produce 4 kWh of heat using 1 kWh of electricity, resulting in an efficiency of 4 that is measured through its coefficient of performance (COP). When considering energy intensity as the energy input to the system divided by the energy output, the energy intensity would be 0.25 $kWh_{ele}/kW_{th}$.

Table 4 presents an estimate of the energy intensity of using air-water heat pumps in reference single-family houses across different EU countries. Additionally, the estimation includes the energy intensity of using a gas boiler for comparison. For the heat pump, we calculated the electricity used to run the heat pumps and divided it by the delivered heat. In the case of the gas boiler, we calculated the gas use and divided it by the delivered heat. The energy intensity of an air-water heat pump ranges from 0.33 to 0.45 in selected single-family houses. Comparing this with the energy intensity of gas boilers used in the same houses, which is greater than one. The energy intensity of the heat pump is significantly lower than that of a gas boiler, mainly due to its efficiency, which in these cases is 2.5-4 times more efficient than gas boilers.

The analysis indicates the amount of greenhouse gas emissions emitted per kWh of delivered heat. This calculation is based on the application of national emissions factors from the electricity grids for heat pumps (from (EEA 2022) and applying 202 $gCO_2/kWh$ for gas boilers (IPCC 2006). The results reveal significant differences among Member States, ranging from 106 $kgCO_2$ to over 4 000 $kgCO_2$ per kWh delivered heat. Notably, Estonia exhibits the highest emissions intensity when using air-water heat pumps, attributed to the high $CO_2$ emissions factor for electricity production.[49] The integration of more renewables into the electricity grid will lead to reduced emissions intensity when operating a heat pump.

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[49] We applied the emissions factor of 621 $gCO_2/kWh$ for Estonia. The value is from 2020 and might be lower today (EEA 2022).

**Table 4:** Energy intensity and emissions intensity per delivered heat for air-water heat pumps and gas boiler in single-family houses in AT, BG, CZ, DK, EE, FI, FR, DE, LT and SK

| **Country** | **Size** | **Heat demand** | **Energy intensity** Air-water heat pump | **Energy intensity** Gas boiler | **$CO_2$ intensity** Air-water heat pump | **$CO_2$ intensity** Gas boiler |
|---|---|---|---|---|---|---|
| - | $m^2$ | $kWh_{th}/m^2$ | $kWh_{input}/kWh_{th}$ | $kWh_{input}/kW_{th}$ | $kgCO_2/kWh_{th}$ | kgCO2/$kWh_{th}$ |
| AT | 153 | 116 | 0.41 | 1.04 | 566.7 | 3 732.3 |
| BG | 111 | 83 | 0.35 | 1.03 | 1 146.1 | 1 926.9 |
| CZ | 145 | 94 | 0.38 | 1.04 | 2 030.3 | 2 875.2 |
| DK | 122 | 121 | 0.33 | 1.23 | 588.5 | 3 680.9 |
| EE | 187 | 96 | 0.41 | 1.04 | 4 602.6 | 3 798.0 |
| FI | 106 | 124 | 0.45 | 1.03 | 377.9 | 2 741.5 |
| FR | 103 | 49 | 0.35 | 1.03 | 105.9 | 1 064.1 |
| DE | 150 | 176 | 0.35 | 1.05 | 2 945.1 | 5 608.0 |
| LT | 187 | 89 | 0.40 | 1.04 | 1 097.2 | 3 490.5 |
| SK | 187 | 77 | 0.40 | 1.04 | 604.1 | 3 025.5 |

*Source: Own estimation based on (Toleikyte, et al. 2023), (EEA 2022), (IPCC 2006).*

*Note: The green-red scale indicate the carbon intensity, with darker red meaning higher emissions.*

## Labour productivity

The labour productivity of the heat pump manufacturing sector, measured as turnover per employee, decreased marginally from EUR 153 846 in 2021 to EUR 129 864 in 2022, representing a decline of approximately 15.6%. It might be possible to improve labour productivity through digitalisation and automation, especially in Europe, where labour costs are higher than in the Asia-Pacific region. Modular designs and standardised components could further reduce manufacturing times (RHC and EHPA 2021). Those trends imply correspondingly slower future growth in heat pump manufacturing employment. In the assembly of heat pumps, labour productivity increased by 32% during the period 2015-2021 in the EU, as turnover grew faster than employment (JRC based on EHPA and Orbis). Based on a selection of sites, an average of 5.5 jobs are created for each thousand units of heat pump manufacturing capacity that is added (see Table 5).

**Table 5:** Labour productivity of ongoing investments in heat pump manufacturing capacity in the EU, 2023

| **Company** | **Country** | **New jobs** | **Thousand additional units** | **Jobs per thousand units** |
|---|---|---|---|---|
| Daikin | Poland | 1 000 | 220 | 5 |
| Stiebel Eltron | Germany | 400 | 240 | 2 |
| Bosch | Portugal | 300 | 150 | 2 |
| Clivet (Midea) | Italy | 700 | 100 | 7 |
| Hoval | Slovakia | 500 | 30 | 17 |
| Atlantic | France | 300 | 170 | 2 |
| Aira | Poland | 2 000 | 500 | 4 |

*Source: JRC analysis based on company websites and EHPA.*

While manufacturing is an important component of the heat pump industry, the installation and maintenance phases account for a significantly larger share of job creation potential, highlighting the importance of these segments in driving employment growth. Comparing data on sales, stock and employment, we can calculate that a manufacturing worker assembles around 300 heat pumps per year. In comparison, an installer deploys around 61 heat pumps, and a technician maintains or services a stock of around 1 100.

Productivity at the installation stage could be improved through standardisation, economies of scale, digitalisation or plug-and-play technology. In both manufacturing (e.g. components) and installation (e.g.

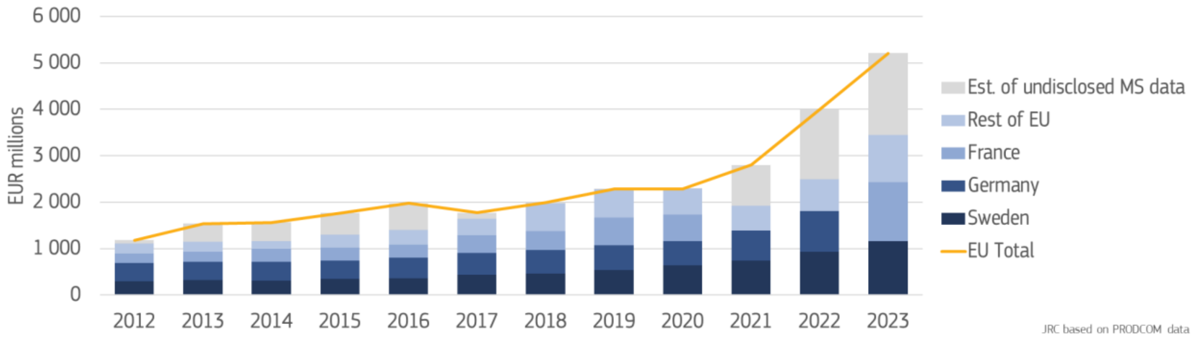
digitalisation), heat pump deployment might also benefit from greater alignment of standards internationally, for example, between the EU and the United States (Hedberg and Khakova 2023).

## 3.7 EU production data

In 2023, the value of EU heat pump production increased by 30%,[50] reaching more than EUR 5 billion (Figure 36). On the three-year average, Germany, France and Sweden are the top EU producers (Figure 37). Sweden has steadily increased production over the last decade, and in 2023, the production value reached almost EUR 1.2 billion, notably hosting the manufacturers like Nibe and Aira. Among smaller producing countries, production in the Czech Republic increased by 217% in 2023 to EUR 400 million.

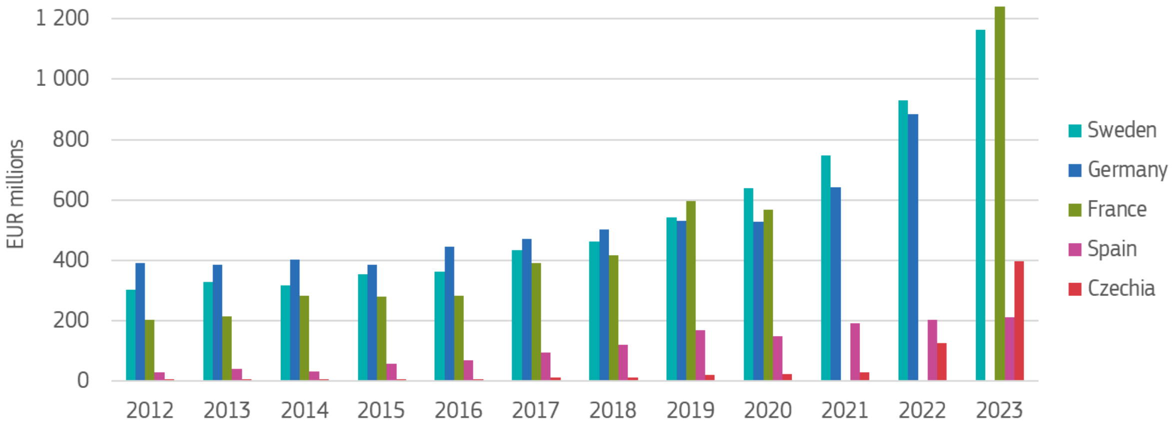
The increasing trends are largely a result of target announcements, political priorities and specific policies. For instance, France has set a target to increase manufacturing fourfold to 1.3 million heat pumps by 2030, with 300 000 for export. Furthermore, France has introduced a package of measures to meet President Macron's targets for reducing greenhouse gas emissions by 2030, including the central plan of producing one million heat pumps in France by 2027. The government is implementing various strategies to accelerate manufacturing capacity and heat pump installations, such as providing tax credits to manufacturers and assemblers, establishing a one-stop shop, offering financial support for households, simplifying standards to facilitate the installation of heat pumps in collective housing, supporting research and development, and developing a skills adaptation plan, particularly for installers.

**Figure 36**: EU production value and top producers among the Member States disclosing data [EUR Million]



*Source: JRC based on PRODCOM data. Please note that not all countries consistently disclose their annual data, with France withholding information for 2021 and 2022, and Germany for the year 2023.*

**Figure 37:** EU top five producers by the production value



*Source: JRC based on PRODCOM data. Please note that not all countries consistently disclose their annual data, with France withholding information for 2021 and 2022, and Germany for the year 2023.*

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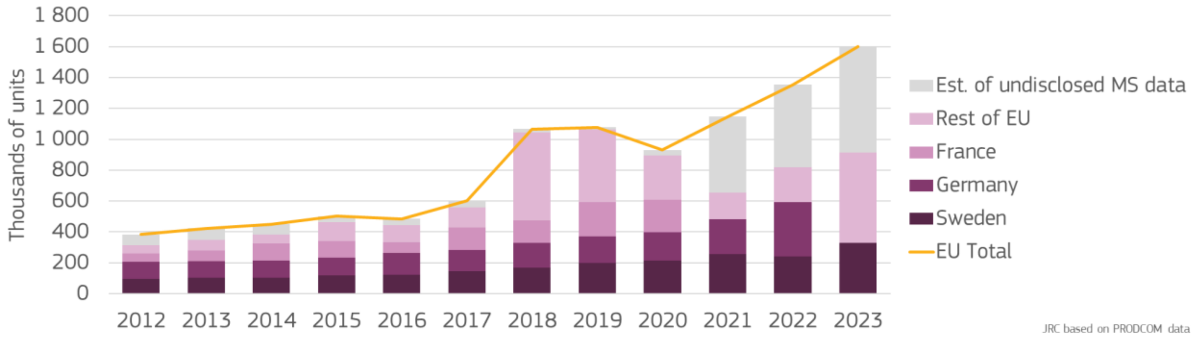
[50] Prodcom code 28251380.

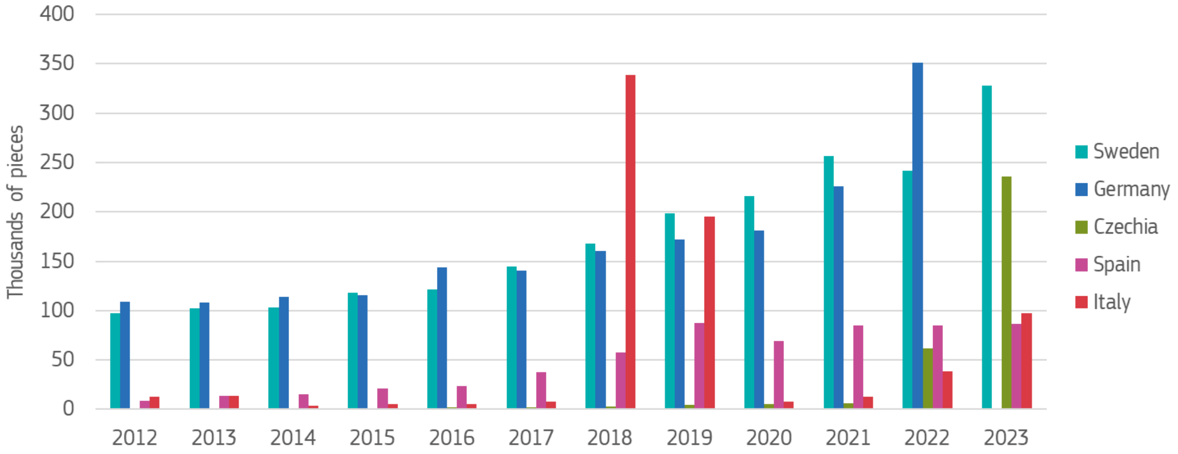
In terms of quantities, EU production increased by 18%, reaching 1.6 million units. Sweden and France were the top producers in 2023, while Germany has not disclosed their production data for that specific year.

**Figure 38:** EU production in quantities (thousand units)



Source*: JRC based on PRODCOM data. Please note that not all countries consistently disclose their annual data, with France withholding information for 2021 and 2022, and Germany for the year 2023.*

**Figure 39:** EU top producers by quantity



*Source: JRC based on PRODCOM data.*

### Recent investment announcements

Manufacturers have invested significantly in the EU to meet the anticipated increase in demand. According to the EHPA, the expected capacity investments in the EU amounts to around EUR 7 billion until 2030 (EHPA 2024).

**Table 6:** A selection of investment plans from key EU manufacturers

| Company | Country | Total (EUR millions) | New or expansion | Start and final year |
|---|---|---|---|---|
| Saunier Duval | FR | 9.3 | Expansion | 2020-2023 |
| Vaillant | SL | 120 | New | 2022-2023 |
| Vaillant | PL | 200 | New | 2022-2023 |
| Vaillant | ES |  | New | - |
| BDR Thermea | FR | 70 | Expansion. | 2023-2026 |
| BDR Thermea | TR | 70 |  | 2023-2026 |
| BDR Thermea | IT | 70 | New | 2023-2026 |
| BDR Thermea | NL | 70 | New | 2023-2026 |
| BDR Thermea | ES | 70 | Expansion. | 2023-2026 |
| Daikin | BE | 23 | Expansion. | 2022-2025 |
| Daikin | FR |  | New | 2022-2024 |
| Daikin | DE | 827 | Expansion. | 2022-2025 |
| Daikin | PL | 300 | New | 2022-2025 |
| Daikin | CZ | 50 | Expansion. | 2022-2025 |
| -Intuis | FR | 6 |  | 2022-2024 |
| Stiebel Eltron | DE | 600 | Expansion | 2021-2026 |
| Bosch | DE | 330.2 |  | 2022-2025 |
| Bosch | EU | 1000 |  | 2023-2030 |
| Bosch | PL | 255 | New | 2024-2025 |
| Bosch | PT | 100 | Expansion | 2023-2026 |
| NIBE | SE | 460 |  | 2023-2026 |
| Ecoforest | ES | 10 |  | - |
| Ariston |  |  |  | - |
| Atlantic | UK | 58 | New | 2023- |
| Kensa | UK | 70 | Expansion | 2020- |
| Viessmann (Carrier) | PL | 800 |  | 2022-2025 |
| Viessmann (Carrier) | PL | 200 | New | 2022-2025 |
| Mitsubishi | TR | 109 | Expansion | 2022-2024 |
| Qvantum | HU | 38 | New | 2023-2024 |
| Clivet (Midea) | IT | 60 | New | 2022-2024 |
| Hoval | SL | 60 | Expansion | 2023-2024 |
| Atlantic | FR | 120 | Expansion | 2022- |
| Aira | PL | 300 | New | 2024- |
| Panasonic | CZ | 145 | Expansion |  |

*Source: EHPA and JRC compilation.*

The ramp-up of manufacturing is a combination of adding new production lines at existing sites, converting lines at existing sites (e.g. from boilers to heat pumps), and constructing some new production sites. In some cases, investments in RD&I capacity are made simultaneously. Smaller manufacturers are also increasing their capacity at very fast rates but may struggle to achieve the same economies of scale as larger competitors.

The temporary and targeted relaxation of state aid rules announced by the Commission in March 2023 may be helping. Member States are allowed to subsidise part of the investment cost in production capacity for heat pumps and other clean energy technologies, up to a maximum of EUR 150 million for a single company in more prosperous regions and up to EUR 350 million in less affluent regions (EC in Deutsche Bank Research, 2023).

The key influential factors when deciding to expand or locate manufacturing in the EU are (see Eunomia, 2024):

- Clear strategy and commitment from the national governments;
- Access to skilled and affordable labour;
- Additional EU standards and quality requirements on hydronic heat pumps (those that work with radiators or underfloor heating);
- Nearest to point of use;
- Good transport links if not near the point of use;
- Low-cost space and enough space for manufacture.

Based on a survey of EU manufacturers carried out by Eunomia (ibid), there is unused production capacity available. While some EU component manufacturers are currently at full capacity, there remains untapped potential in the assembly of heat pumps, provided that the required components are accessible. Stakeholders estimate that approximately 20% of the remaining capacity could be leveraged. It is important to note that, at the time of data collection (late 2022 and early 2023), the global chip shortage affected various industries, including the heat pump sector, resulting in knock-on shortages of critical components such as heat exchangers and fans.

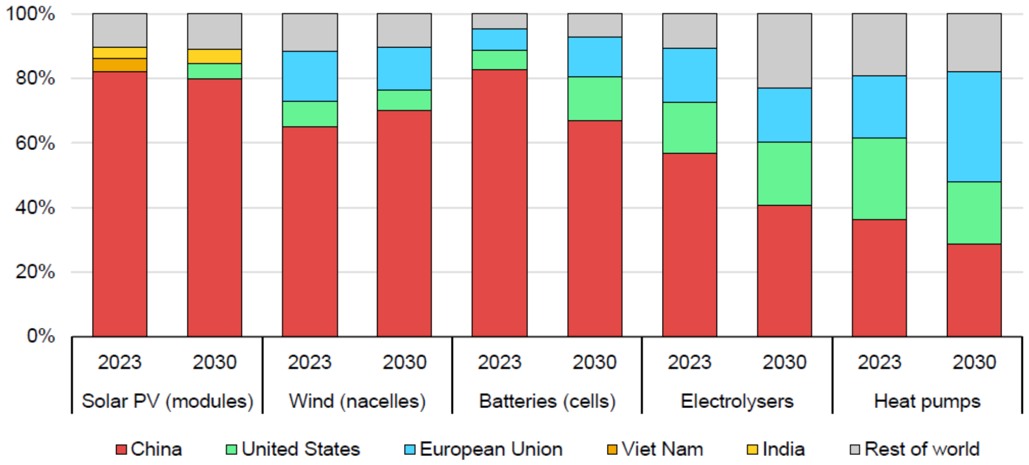
# 4 EU positioning and competitiveness

## 4.1 World and EU market leaders

In 2021, the world's heat pump production capacity, excluding air conditioners, reached 120 GW (IEA 2023). In 2022, European manufacturing capacity was 22 GW (Bruegel 2024).[51]

China is currently the leader globally, accounting for more than 35% of total manufacturing capacity, followed by the United States with approximately 25% (Figure 40). Europe's manufacturing capacity makes up 20% of the world capacity. Compared to other clean energy technologies, the EU is well positioned. Looking ahead to 2030, based on announced manufacturing capacity, Europe is projected to significantly increase its manufacturing capacity and take the lead by 2030. The projected share of manufacturing capacity for Europe is almost 40%. In 2023, the value of EU heat pump production increased by 30%, to more than EUR 5 billion.

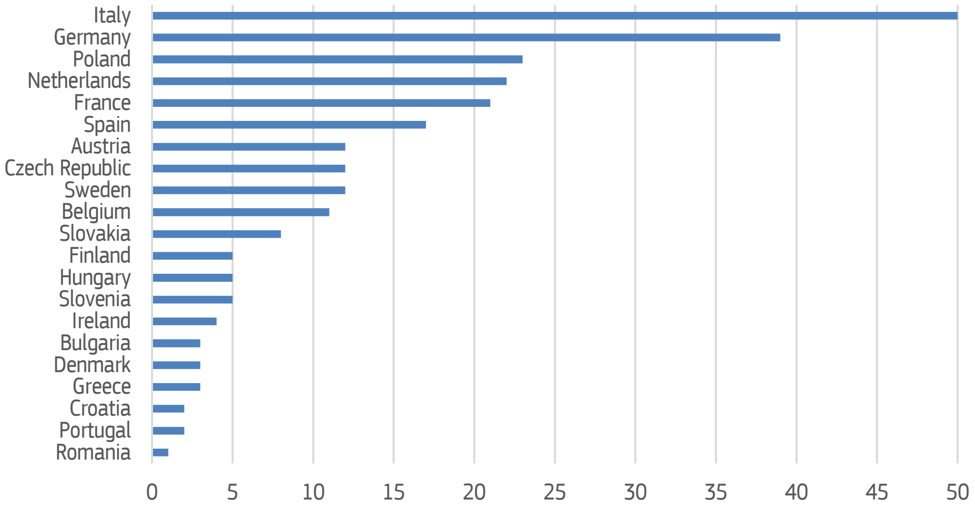
**Figure 40:** Geographical concentration of current and announced manufacturing capacity, 2023-2030



*Source: (IEA, 2024).*

The top ten companies by the number of locations in the EU are Daikin, followed by Bosch, Viessmann, Vaillant, Nibe, BDR Thermea, Stiebel Eltron, Mitsubishi Electric, Panasonic and Atlantic (section 3.4). The largest number of sites is in Italy, with Germany, Poland, France and the Netherlands close behind (Figure 41).

**Figure 41:** Heat pump manufacturer location in the EU by country



*Source: JRC based on various sources.*

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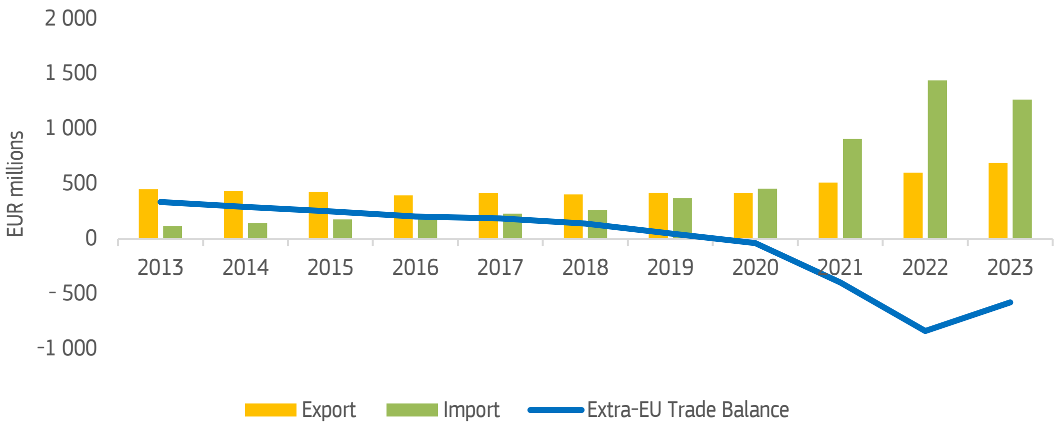
[51] EU, Norway and the UK.

## 4.2 Trade (imports, exports) and trade balance

Until 2020, the EU trade balance of heat pumps was in surplus, meaning that the EU exported more heat pumps than it imported (Figure 42).[52] In 2020, the EU trade balance turned to a deficit for the first time, as a result of increasing extra-EU imports. The extra-EU imports grew from EUR 500 million in 2020 to EUR 1.4 billion in 2022, indicating a penetration of non-EU producers, mainly from China, to the growing EU market. However, in 2023, the EU deficit in trading heat pumps shrank by one-third. More specifically, extra-EU imports decreased by 13%, down to about EUR 1.3 billion, while extra-EU exports increased by 14%, reaching almost EUR 0.7 billion.

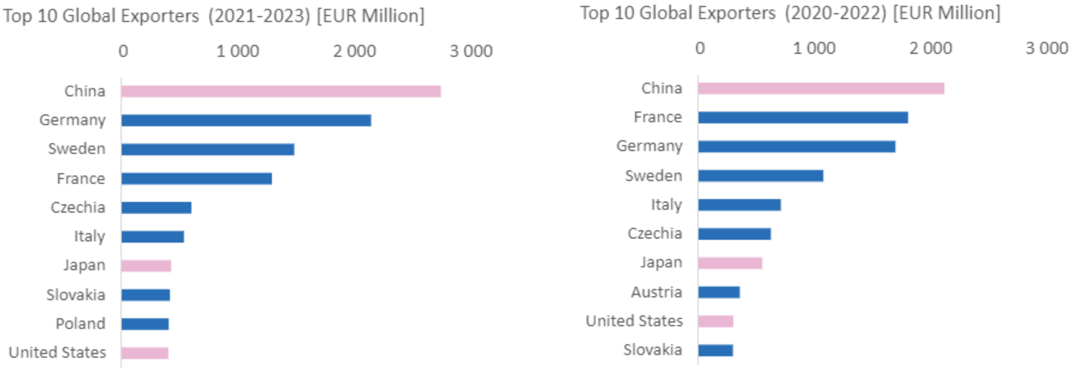
**Figure 42:** Extra-EU trade for heat pumps



*Source: JRC based on COMEXT and COMTRADE data.*

The EU has a strong presence in world trade as extra-EU exports accounted for 29% of world exports during 2020-2022. In the period 2021-2023 however, it decreased to 26% (JRC based on COMEXT and Comtrade data). In that period, China was the biggest exporter, followed by Germany, Sweden and France. If we compare the data for 2020-2022, we see that France was the second largest exporter globally, followed by Germany and Sweden.

**Figure 43:** Top global exporters in the period of 2021-2023 (left) and in the period of 2020-2022 (right) [EUR million]



*Source: JRC based on COMEXT and COMTRADE data.*

The EU is fairly well positioned in the export market, except for the big markets such as Australia, the United States, Mexico, Canada and the United Arab Emirates, where imports from non-EU countries are outpacing those from the EU countries. The largest non-EU importers from the EU are Switzerland, the United Kingdom and Norway.

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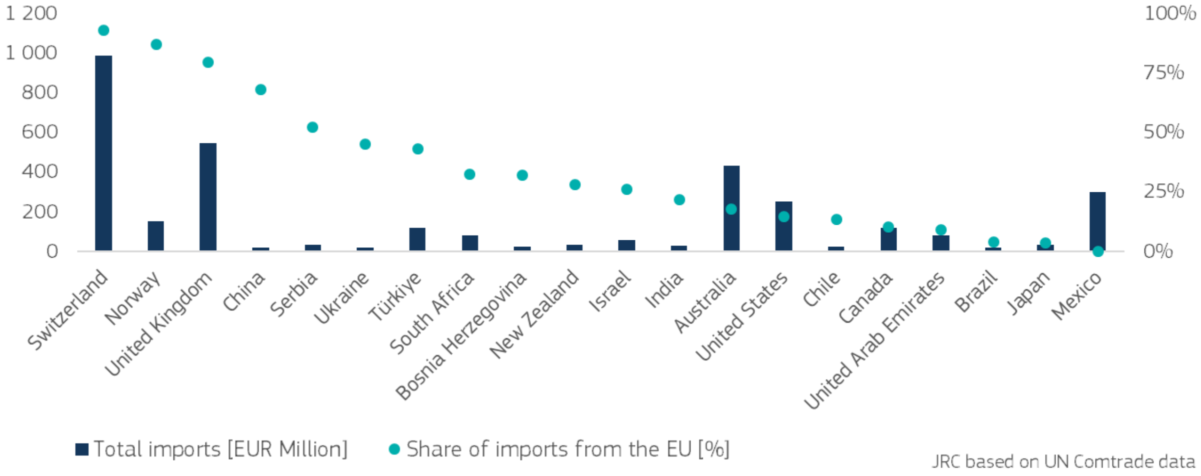
[52] HS 841861– Heat pumps (excl. air conditioning machines of heading 8415).

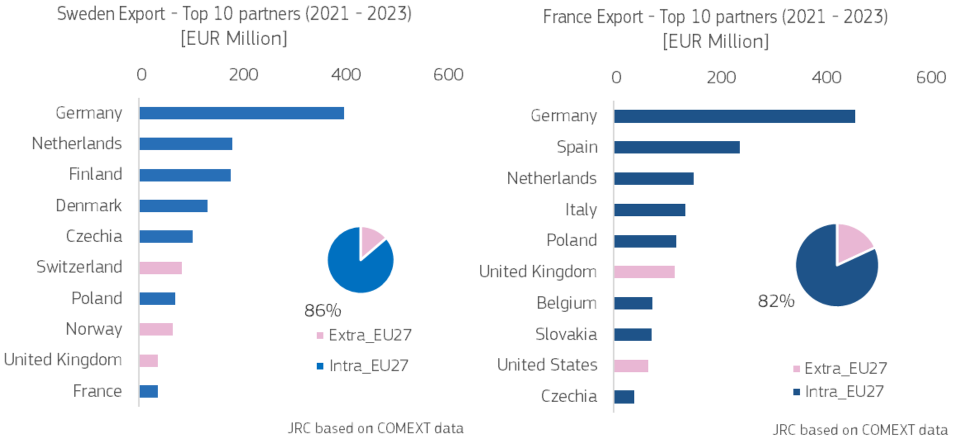
**Figure 44:** Top 20 non-EU importers and their share of imports from the EU (2021-2023)



*Source: JRC based on COMTRADE data*

The non-EU exports are small compared to the EU Single Market, which is the largest "export" market for Member States. EU internal trade plays a significant role in EU countries' exports, as shown in Figure 45, as the largest EU exporters Germany, Sweden and France are mainly serving neighbouring markets.

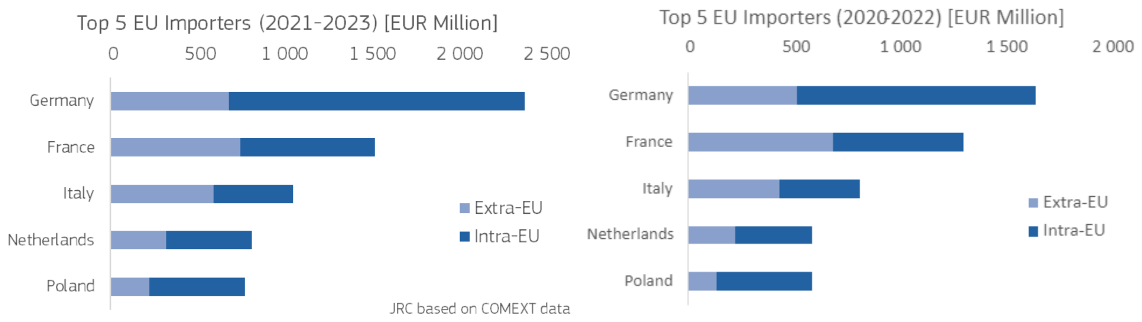
**Figure 45:** Top exports Sweden and France



*Source: JRC based on COMEXT and COMTRADE data.*

In the period 2021-2023, the EU continued to meet approximately two-thirds of its import needs through intra-EU trade, more specifically, 65% of the total imports were covered by EU manufacturers (in the period 2020-2022, it was 68%). China remained the main non-EU exporter to the EU. Even though EU imports from China decreased by a quarter in 2023, China still accounted for 58% of total extra-EU imports for 2021-2023. The top five EU importers were Germany, France, Italy, the Netherlands and Poland. If we compare the periods 2021-2023 and 2020-2022, we see that total imports have increased in all countries.

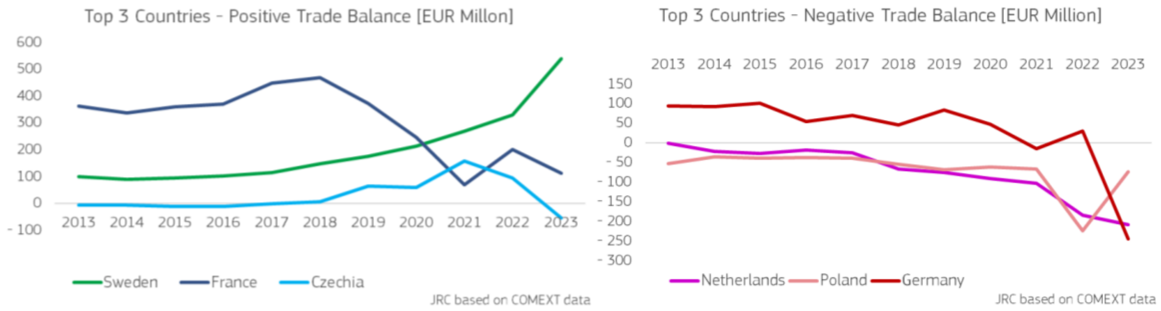
**Figure 46:** Top 5 EU importers



*Source: JRC based on COMEXT and COMTRADE data.*

In the period 2021-2023, Sweden, France and the Czech Republic were the Member States with the largest trade surpluses, meaning they exported more heat pumps than imported. Over the same period, the Netherlands, Poland and Germany, the Member States with the highest trade deficit, brought 52%, 81% and 29% of their extra-EU imports from China respectively.

**Figure 47:** Top 3 countries ranked by their trade balance, positive (left) and negative (right)



*Source: JRC based on COMEXT and COMTRADE data.*

## 4.3 Resource efficiency and dependence in relation to EU competitiveness

At the macro scale, heat pumps are manufactured from similar raw materials to the boilers they replace. Many components are also not specific to heat pumps, and sourcing is closely linked to related sectors such as boiler, air conditioning, and refrigeration manufacturing. Nevertheless, heat pumps are vulnerable to volatility in metals prices and the supply of some components, such as semiconductors and permanent magnets. They contain some strategic raw materials and critical raw materials, from dysprosium with a high supply risk to copper with only a low supply risk.

More widespread integration of smart controls might exacerbate the vulnerability to semiconductor shortages, but smart controls are also necessary in order to maximise the self-consumption of renewables and provide flexibility to the grid. Still, it might be possible for manufacturers to use simpler designs in some areas, such as alternating current fans. The chips used in heat pumps are also not the most highly specialised or advanced types, which means they can sometimes be sourced or repurposed from adjacent manufacturing sectors.

Permanent magnet motors use microchips to vary the pump speed and reduce energy consumption. Most permanent magnets contain critical raw materials such as neodymium and dysprosium, whose recycling is possible but today only performed in the EU on a small scale or in the context of research projects. Permanent magnets are a potential supply risk because there are few short-term alternatives in case of disruptions to imports from China. There is also a risk of non-compliance through using less efficient motors that do not contain permanent magnets. As with semiconductors, permanent magnets are deployed in a wide variety of other products, notably wind turbines and electric vehicles, so a holistic approach is needed.

EU’s shift towards natural refrigerants in heat pumps represents a strategic move to reduce the environmental impact of high global warming potential refrigerants like HFCs and HFOs. This transition is enforced through tightening regulations, such as the F-Gas Regulation aiming for a 98% reduction of high GWP refrigerants by 2050 and potential restrictions on PFAS. Adopting natural refrigerants can significantly cut greenhouse gas emissions linked to heat pumps, which are notable during their lifecycle due to refrigerant leakage. The EU's proactive stance could boost its industrial competitiveness by fostering innovation and positioning EU manufacturers as leaders in low-emitting heat pump technologies. In the short term, the move towards natural refrigerants can trigger price increases of heat pumps which risk harming the market growth and competitiveness of EU manufacturers. However, as global markets increasingly demand sustainable products, early adopters within the EU could gain a competitive advantage, potentially leading to long-term economic benefits and growth.

Some of the main materials used in a heat pump are various types of steel (reinforcing, low-alloyed, stainless), copper and elastomers (Table 7 shows an example of an air-source heat pump). Compared to a representative gas boiler, the heat pump uses a greater quantity of copper, some additional materials, and notably a refrigerant. Steel is used to make the compressor, housing heat exchangers and piping of a heat pump. Copper is used to produce the heat exchanger, piping, electric cables and expansion valves.

Large heat pumps (for industrial and DHC applications) are made from similar materials. However, materials may be used in different combinations and proportions depending on the temperature and refrigerant used.

**Table 7:** Exemplary material requirements of an air-source heat pump and a gas boiler, each with a capacity of 10 kW (kg)

| **Raw materials** | **Air-source heat pump** | **Gas boiler** |
|---|---|---|
| | (kg) | (kg) |
| Steel | 157 | 120 |
| Copper | 36.6 | 3 |
| Elastomers | 16 | |
| Refrigerant (R134A) | 4.9 | |
| Polyolester oil | 2.7 | |
| Polyvinyl Chloride (PVC) | 1.6 | |
| High Density Polyethylene (HDPE) | 0.5 | 0.9 |
| Rockwool | | 8 |
| Aluminium | | 7.5 |
| Brass | | 0.1 |

*Source: (Azapagic 2012).*

Copper is used in heat pumps primarily because of its excellent electrical and thermal conductivity, corrosion resistance and workability (brazing). Different types of residential heat pumps contain the following amounts of copper by product category:

**Table 8:** Copper use by type of heat pump

| | **Copper tubes** | **Copper wire** | **Other** | **Total** |
|---|---|---|---|---|
| | (kg) | (kg) | (kg) | (kg) |
| Air to water split heat pumps (10-12kW) | 15.8 | 4,5 | 1 | 21.3 |
| Air to water monoblock heat pumps (10-12kW) | 10.8 | 5.5 | 0.8 | 17.1 |
| Air to air split heat pump (AC), 5.2 kW/room | 11.4 | 3.8 | 0.7 | 15.9 |
| Ground to water heat pump, (10-15 kW) | 3 | 4.6 | 6.4 | 14 |

*Source: European Copper Institute, 2024.*

# 5 Conclusions

Heat pumps are a key technology for enabling the clean energy transition and achieving the EU's carbon neutrality goal by 2050. Additionally, they play a crucial role in reducing the EU's dependence on Russian fossil fuels. In the buildings sector, heat pumps will contribute significantly to the shift away from fossil fuel boilers. In the industry, heat pumps are an important clean energy technology for decarbonising process heat. While they are already a well-proven technology for heat supply temperatures below 100°C, their deployment in industry is limited for process heat above 100°C, although various solutions are under development.

Despite their potential, there are still barriers from the demand side. For the buildings sector, the main obstacles include the relatively high up-front cost of a heat pump (in the absence of subsidy or finance options), high electricity-to-gas ratios due largely to unfavourable tax treatment, administrative challenges (such as the high hurdle required to make an investment decision in an apartment building), and a lack of skilled installers. The main barriers in the industry and DHC sectors are uncertain fuel price developments, political uncertainties, and a lack of funding for RD&I projects.

As of 2023, 21.5 million heat pumps were installed in Europe. The heat pump market experienced a slowdown in sales in 2023, with the pace declining by 7% compared to record levels seen in the preceding year. However, production data shows positive trends, with the value of EU heat pump production increasing by 30% in 2023, reaching more than EUR 5 billion. The heat pump industry is the largest renewable energy sector in terms of employment, with a 10% increase in employment in 2022, though followed by (smaller) cuts and hiring freezes in 2023.

Between 60% and 73% of heat pumps installed in Europe are produced in the EU. From 2013 to 2020, the EU trade balance for heat pumps was in surplus, i.e. more heat pumps were exported than imported. In 2020 the trade balance turned negative due to increasing extra-EU imports. The deficit decreased in 2023 after two further years of growth.

Europe's manufacturing capacity accounts for 20% of world capacity, positioning the EU well in the world market. Looking ahead to 2030, based on announced manufacturing capacity, Europe is projected to significantly increase its manufacturing capacity and take the lead in 2030. The EU is fairly well positioned in the export market, with Switzerland, the United Kingdom and Norway being the largest non-EU importers from EU producers.

Recent announcements of new investments from key leading companies in the heat pump sector are encouraging signs of trust in future market developments. However, there are vulnerabilities in the main value chain related to skills and labour, and sporadic supply chain bottlenecks.

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## List of abbreviations and definitions

| | |
|---|---|
| CETO | Clean Energy Technology Observatory |
| $CO_2$ | Carbon dioxide |
| COMEXT | EU’s database on international trade in goods |
| COMTRADE | The United Nations Comtrade is a repository of official international trade statistics |
| COP | Coefficient of Performance |
| CRMs | Critical raw materials |
| DHC | District heating and cooling |
| DHW | Domestic hot water |
| EBEM | JRC’s European Building Energy Model |
| EED | Energy Efficiency Directive |
| EGEC | European Geothermal Energy Council |
| Ehi | European Heating Industry (association) |
| EHP | EuroHeat & Power (association) |
| EHPA | European Heat Pump Association (association) |
| EPBD | Energy Performance of Buildings Directive |
| EU | European Union |
| F-gases | Fluorinated greenhouse gases |
| GVA | Gross Value Added |
| GWP | Global warming potential |
| HVAC | Heating Ventilation and Air Conditioning |
| IEA | International Energy Agency |
| IEA HPT | IEA's Technology Collaboration Programme on Heat Pumping Technologies |
| JRC | Joint Research Centre |
| LCoE | Levelised Cost of Energy |
| PE | Private Equity |
| PFAS | Per- and polyfluoroalkyl substances (i.e. “forever chemicals”) |
| PRODCOM | Industrial production statistics are presented annually according to the PRODCOM survey |
| PVC | Polyvinyl Chloride |
| PV-T | Photovoltaic-thermal |
| RD&I | Research, development and innovation |
| RED | Renewable Energy Directive |
| RHC Platform | Strategic Research and Innovation Agenda of the European Technology and Innovation Platform on Renewable Heating and Cooling |
| SCOP | Seasonal Coefficient of Performance |
| SET Plan | EU’s Strategic Energy Technology Plan |
| SSbD | Safe and Sustainable by design |
| TRL | Technology Readiness Level |
| VC | Venture Capital |

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# Annex 1 Summary of data sources

**Table 9**: Data sources

| Theme | Indicator | Main data source |
|---|---|---|
| Technology maturity status, development and trends | Technology Readiness Level | JRC |
| | Installed capacity and energy production, sales and projections | Industry associations (mainly EHPA), Eurostat, JRC modelling |
| | Technology costs | JRC |
| | Public and private RD&I funding | JRC based on IEA (public) and Pitchbook (private) |
| | Patenting trends | Patstat |
| | Scientific publication trends | JRC TIM |
| | Assessment of RD&I project developments | SET-Plan, CORDIS |
| Value chain analysis | Turnover | EurObserv'ER |
| | Gross Value Added | EurObserv'ER |
| | Environmental and socio-economic sustainability | Various sources |
| | Role of EU companies | JRC |
| | Employment | EurObserv'ER |
| | Energy intensity and labour productivity | JRC, Eurostat |
| | EU industrial production | PRODCOM |
| World markets and EU positioning | EU position in global market share | JRC |
| | EU trade (imports, exports) and trade balance | COMEXT |
| | Resource efficiency and dependencies (in relation to EU competiveness) | JRC |

# Annex 2 Sustainability assessment

**Table 10.** Application of the sustainability assessment framework to heat pumps

| Sustainability aspect | Indicators | Assessment of heat pumps |
|---|---|---|
| **Market trend** | - Demand over time<br>- EU market share | Described elsewhere in this report. |
| **Trade and trade balance** | - EU share in global exports<br>- Extra-EU trade balance | Described elsewhere in this report. |
| **Cost of energy** | For power generation technologies: Levelised Cost Of Electricity (LCOE)<br>For storage technologies: Levelised Cost of Storage (LCOS) | Described elsewhere in this report. |
| **Critical Raw Materials (CRMs)** | The EC method includes various indicators concerning import reliance, governance, supply concentration, etc. | Described elsewhere in this report. |
| **Technology-specific permitting requirements** | | Planning requirements with respect to noise and aesthetics vary by Member State; additional requirements with respect to drilling in the case of some ground-source heat pumps. In the DHC and industrial segments, permitting requirements might be less strict for heat pumps than their combustion-based alternatives. |
| **Skills and technology development** | **Skill development** concerns four categories:<br>1. Skills gap, the distance between the skill level in society and the skills required for the technology development and deployment;<br>2. Skill obsolescence, the loss of skills due to the lack of use, or the risk the skills become irrelevant;<br>3. Skill shortages, when there are jobs, but no qualified staff in the community;<br>4. Over and under skilling, when people have skills above or below the requirements.<br>**Technology transfer and development** is the process for converting research into economic development, or for using technology, expertise or know-how for a purpose not originally intended by the developing organisation. It is fundamental for the improvement of social conditions and to prevent further environmental damage related to old technology use. | Described elsewhere in this report. |
| **Resilience** | Resilience is the ability to reduce and withstand the magnitude and duration of disruptive events, which include the capability to anticipate, adsorb adapt to or rapidly recover from such an event. | See CETO 2023, section 5.3 |

| Sustainability aspect | Indicators | Assessment of heat pumps |
|---|---|---|
| | This aspect can be qualitatively assessed taking into account the following aspects: diversity in the market, suppliers and technologies; risk reduction; adaptive capacity (Zamagni 2019).<br>The quantification of resilience is still under discussion. Potential indicators include supply chain concentration (geographic, market, technologies) and exposure to risk (trade, natural, technical, geopolitical). | |
| **Resource efficiency and recycling** | e.g.<br>Minimum recycling efficiency<br>Recycled content<br>Durability<br>Removability and “replaceability” | See CETO 2023, section 5.4 |
| **Energy balance** | Energy Pay Back Time (EPBT)<br>Energy Return on Energy Invested (EROI)<br>Energy consumption per technology | No information on energy used in manufacturing.<br>For the use phase, see elsewhere in this report. |
| **Climate change** | Global warming potential (GWP100) | See CETO 2023, section 5.1 |
| **Ozone depletion** | Ozone Depletion Potential (ODP) | There are a small number of Ecodesign preparatory studies and Life-Cycle Assessments but insufficient. Energy consumption in the use phase dominates environmental impacts. |
| **Particulate matter / Respiratory inorganics** | Human health effects associated with exposure to $PM_{2.5}$ | “ |
| **Ionising radiation, human health** | Human exposure to $^{235}U$ | “ |
| **Photochemical ozone formation** | Tropospheric ozone concentration increase | “ |
| **Acidification** | Accumulated Exceedance (AE) | “ |
| **Eutrophication, terrestrial** | Accumulated Exceedance (AE) | “ |
| **Eutrophication, aquatic freshwater** | Fraction of nutrients reaching freshwater end compartment (P) | “ |

| Sustainability aspect | Indicators | Assessment of heat pumps |
|---|---|---|
| **Eutrophication, aquatic marine** | Fraction of nutrients reaching marine end compartment (N) | “ |
| **Land use** | Soil quality index$^4$ aggregating: Biotic production, Erosion resistance, Mechanical filtration and Groundwater replenishment | No significant impacts on land use have been identified. |
| **Water use** | User deprivation potential (deprivation weighted water consumption) | “ |
| **Resource use, minerals and metals** | Abiotic Depletion Potential (kg antimony-equivalent) | “ |
| **Resource use, energy carriers** | Abiotic Depletion Potential (fossil fuels) | Heat pumps generally replace fossil boilers; this is their key contribution to mitigating environmental impacts. |
| **Biodiversity** | Biodiversity loss is still under refinement in the LCA community, with several methods being developed. These methods address three drivers: land-use change, climate change and environmental pollution, and water use. | No information available |
| **Child labour** | Social Life Cycle Impact Assessment (Type I).[53] The assessment should look at the main suppliers and countries involved in the production of raw materials, intermediate products and components used in heat pumps.<br>Percentage of working children under the legal age or 17 years old (total, male and female) – country level | Considering the raw materials used in heat pumps, South Africa (manganese) and China (nickel) are countries at stake (Mancini et al., 2020). |
| **Forced labour** | Social Life Cycle Impact Assessment (Type I). The assessment of this aspect can be performed looking at the main suppliers and countries involved in the production of raw materials, intermediate products and components used in heat pumps.<br>Frequency of forced labour (estimated prevalence of population in modern slavery, victims per 1 000 population) - country level | Considering the raw materials used in heat pumps, South Africa (manganese) and China (nickel) are countries at stake (Mancini et al., 2020).<br>The Global Slavery Index provides the following values for the prevalence of forced labour, i.e. the “*estimated proportion of population living in modern slavery per thousand people*”. These values can be translated in risk levels using the reference scale adopted in Maister et al., 2020 (Table 4). The risk is very low in the case of South Africa, and is low in the case of China. |
| **Equal opportunities / discrimination** | Social Life Cycle Impact Assessment (Type I). The assessment of this aspect can be performed looking at the main suppliers and countries involved in the production of raw materials, intermediate products and components used in heat pumps.<br>Gender wage gap (%) - country level<br>Women in the labour force (ratio) – country/sector level | Considering the raw materials used in heat pumps, South Africa (manganese) and China (nickel) are the main countries at stake (Mancini et al., 2020).<br>For the indicator “gender wage gap by occupation (%)”, values can be retrieved from ILOSTAT but data is available only for one country:<br>South Africa: 9.5 in 2019 (related to “Skill level: total”). The risk level for this value, using the reference scale |

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[53] The Type I Social Impact Assessment method aims at assessing the social performance or social risk of the system under investigation using a reference scale (UNEP 2020).

| Sustainability aspect | Indicators | Assessment of heat pumps |
|---|---|---|
| | | adopted in Maister et al. (2020), is “low risk”.<br>Concerning the indicator “ratio of women in the labour force” values can be retrieved from S-LCA databases. The following values and risk levels can be observed for the countries and sector under investigation (year 2015):<br>- South Africa, mining sector: 0.39: high risk<br>- China: metal processing sector: 0.89: very low risk. |
| **Freedom of association and collective bargaining** | Social Life Cycle Impact Assessment (Type I). The assessment of this aspect can be performed looking at the main suppliers and countries involved in the production of raw materials, intermediate products and components used in heat pumps.<br>Right to strike / Right to association / Right of collective bargaining (point in scale) - Country level<br>Trade union density (%) - Country level | Considering the raw materials used in heat pumps, South Africa (manganese) and China (nickel) are the main countries at stake (Mancini et al., 2020).<br>For the indicator “trade union density (%)”, values can be retrieved both from ILOSTAT and S-LCA databases. The following values and risk levels apply to the countries of interest:<br>South Africa: 19.1% (2019) very high risk<br>China: 44.2% (2017) medium risk |
| **Working hours** | Social Life Cycle Impact Assessment (Type I). The assessment can be performed looking at the main suppliers and countries involved in the production of raw materials, intermediate products and components used in heat pumps.<br>Hours of work per employee and week (hours)<br>Country/sector level | Considering the raw materials used in heat pumps, South Africa (manganese) and China (nickel) are the main countries at stake (Mancini et al., 2020).<br>For the indicator “Mean weekly hours actually worked per employed person, by sex and economic activity”, values can be retrieved from ILOSTAT, but data is available only for one country:<br>South Africa, industry: 42.3 hours : low risk |
| **Fair salary** | Social Life Cycle Impact Assessment (Type I). The assessment of this indicator can be performed looking at the main suppliers and countries involved in the production of raw materials, intermediate products and components used in heat pumps.<br>Sector average wage, per month<br>Living wage, per month<br>Minimum wage, per month (EUR/month)<br>Country/sector level | Considering the raw materials used in heat pumps, South Africa (manganese) and China (nickel) are the main countries at stake (Mancini et al., 2020).<br>The PSILCA database provides a risk assessment for a set of five indicators related to wage. Among them, the sector average wage is the only sector-specific indicator.<br>The associated risk levels for the countries of interest for batteries are the following:<br>- South Africa: 1268 USD (2017), very low risk<br>- China: 843 (2016), very low risk |
| **Health and safety** | Social Life Cycle Impact Assessment (Type I). The assessment of this aspect can be performed looking at the main suppliers and countries involved in the production of raw materials, intermediate products and components used in heat pumps. Can be complemented by a literature review on large accident risk along the life cycle and human health impact on local communities.<br>Fatal and non-fatal accidents at workplace (per 100 000 employees)<br>Country/sector level | Considering the raw materials used in heat pumps, South Africa (manganese) and China (nickel) are the main countries at stake (Mancini et al., 2020).<br>For the indicator “Rates of fatal accidents at workplace” and “Rates of non-fatal accidents at workplace”, values can be retrieved from ILOSTAT (SDG indicator 8.1.1) and risk assessment can be derived based on the reference scale in table 4. However, in the case of countries of interest for heat pumps, no data is available. |

| Sustainability aspect | Indicators | Assessment of heat pumps |
|---|---|---|
| **Responsible materials sourcing** | This category should take into account the supply of raw materials, both in terms of mining practices and country of origin. An assessment at technology level can be based on the identification of the countries of origin of the main raw materials and the verification of the list of conflict-affected and high-risk areas. | No information available. |
| **Competition for material resources (including water, land, food) and indigenous rights** | Descriptive, based on narratives and literature review. This aspect should focus on the potential competition for material resources (e.g. land, food, water, minerals) created by the technology under investigation. | No information available. |
| **Contribution to economic development (including employment)** | Social Life Cycle Impact Assessment (Type I). e.g:<br>% of GDP<br>Direct employment (person year/GWh)<br>Total employment (direct+indirect) (person year/GWh)<br>This aspect can include the following subtopics related to the contribution of the sector to:<br>- Added value<br>- Employment creation (both direct and indirect)<br>Education and training opportunities | Described elsewhere in this report. |
| **Affordable energy access** | Descriptive based on literature review. | See discussion elsewhere in the report: heat pumps often reduce operating costs and volatility but for a higher up-front cost in the absence of subsidies or finance. |
| **Public acceptance** | Descriptive, based on literature review. Should also take into account potential impacts on indigenous rights and access to resources. | The Environmental Justice Atlas documents and analyses information about conflicts and struggles over the exploitation of natural resources and the related production processes. It describes five conflicts linked to manganese projects, two for nickel. |
| **Rural development** | Descriptive approach based on literature review. This aspect can into account the following potential repercussions of energy technologies on rural areas:<br>- Employment opportunities<br>- Entrepreneurship and opportunities for local economy (e.g. in terms of diversification, utilisation of agricultural by-products, other income-generating activities)<br>- Improved access to energy for rural population and increased energy security. | Manufacturing facilities are sometimes located in rural areas. Heat pumps are particularly suited to the kind of one-off housing more typical of rural areas. |

*Source: JRC (2024).*

# Annex 3 Energy System Models and Scenarios: POTEnCIA and POLES-JRC

## AN 3.1 POTEnCIA Model

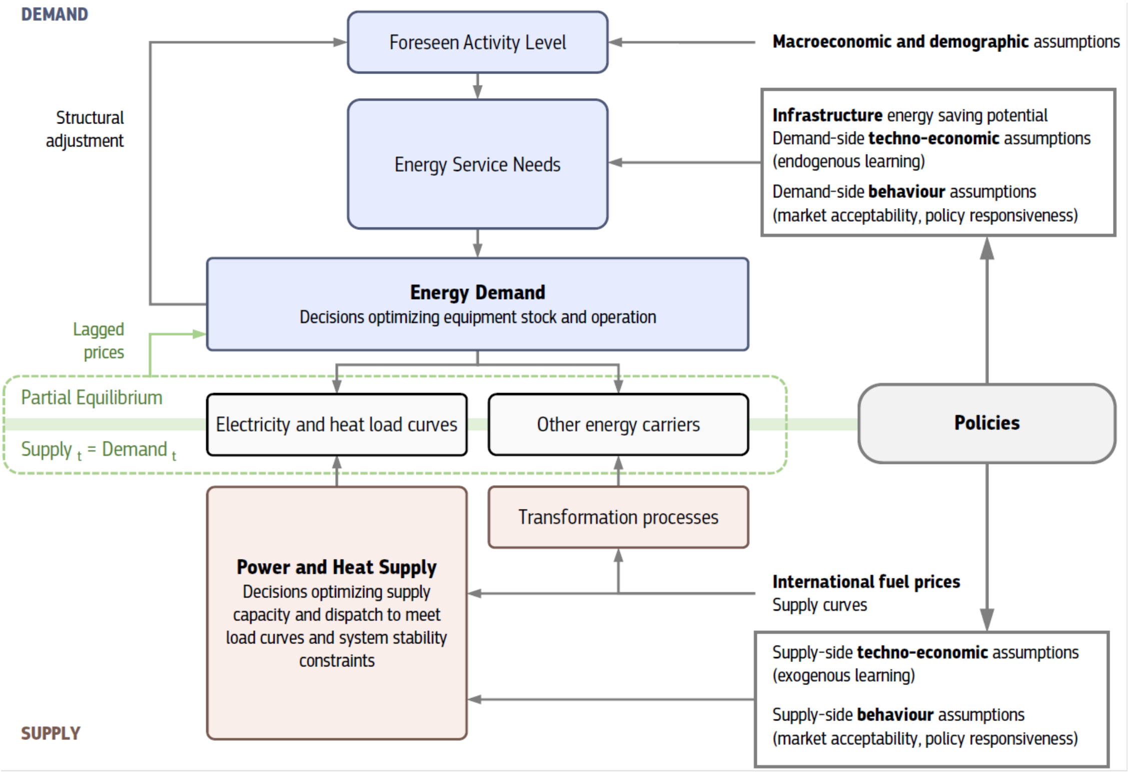
### AN 3.1.1 Model Overview

The Policy Oriented Tool for Energy and Climate Change Impact Assessment (POTEnCIA) is an energy system simulation model designed to compare alternative pathways for the EU energy system, covering energy supply and all energy demand sectors (industry, buildings, transport, and agriculture). Developed in-house by the European Commission's Joint Research Centre (JRC) to support EU policy analysis, POTEnCIA allows for the joint evaluation of technology-focused policies, combined with policies addressing the decision-making of energy users. To this end:

- By simulating decision-making under imperfect foresight at a high level of techno-economic detail, POTEnCIA realistically captures the adoption and operation of new energy technologies under different policy regimes;
- By combining yearly time steps for demand-side planning and investment with hourly resolution for the power sector, POTEnCIA provides high temporal detail to suitably assess rapid structural changes in the EU's energy system;
- By tracking yearly capital stock vintages for energy supply and demand, POTEnCIA accurately represents the age and performance of installed energy equipment, and enables the assessment of path dependencies, retrofitting or retirement strategies, and stranded asset risks.

The core modelling approach of POTEnCIA (Figure 48; detailed in Mantzos et al., 2017, 2019) focuses on the economically-driven operation of energy markets and corresponding supply-demand interactions, based on a recursive dynamic partial equilibrium method. As such, for each sector of energy supply and demand, this approach assumes a representative agent seeking to maximize its benefit or minimize its cost under constraints such as available technologies and fuels, behavioural preferences, and climate policies.

**Figure 48:** The POTEnCIA model at a glance



*Source: JRC adapted from (Mantzos et al., 2019)*

This core modelling approach is implemented individually for each EU Member State to capture differences in macroeconomic and energy system structures, technology assumptions, and resource constraints. The national model implementation is supported by spatially-explicit analyses to realistically define renewable energy potentials and infrastructure costs for hydrogen and $CO_2$ transport. Typical model output is provided in annual time steps over a horizon of 2000-2070; historical data (2000-2021) are calibrated to Eurostat and other official EU statistics to provide accurate initial conditions, using an updated version of the JRC Integrated Database of the European Energy System (JRC-IDEES; Rózsai et al., 2024).

### AN 3.1.2 POTEnCIA CETO 2024 Scenario

The technology projections provided by the POTEnCIA model are obtained under a climate neutrality scenario aligned with the broad GHG reduction objectives of the European Green Deal. As such, this scenario reduces net EU GHG emissions by 55% by 2030 and 90% by 2040, both compared to 1990, and reaches net zero EU emissions by 2050. To model suitably the uptake of different technologies under this decarbonisation trajectory, the scenario includes a representation at EU level of general climate and energy policies such as emissions pricing under the Emissions Trading System, as well as key policy instruments that have a crucial impact on the uptake of specific technologies. For instance, the 2030 energy consumption and renewable energy shares reflect the targets of the EU's Renewable Energy Directive and of the Energy Efficiency Directive. Similarly, the adoption of alternative powertrains and fuels in transport is consistent with the updated $CO_2$ emission standards in road transport and with the targets of the ReFuelEU Aviation and FuelEU Maritime regulations. A more detailed description of the *POTEnCIA CETO 2024 Scenario* will be available in the forthcoming report (Neuwahl et al., 2024).

## AN 3.2 POLES-JRC model

### AN 3.2.1 Model Overview

POLES-JRC (Prospective Outlook for the Long-term Energy System) is a global energy model well suited to evaluate the evolution of energy demand and supply in the main world economies with a representation of international energy markets. It is a simulation model that follows a recursive dynamic partial equilibrium method. POLES-JRC is hosted at the JRC and was designed to assess global and national climate and energy policies.

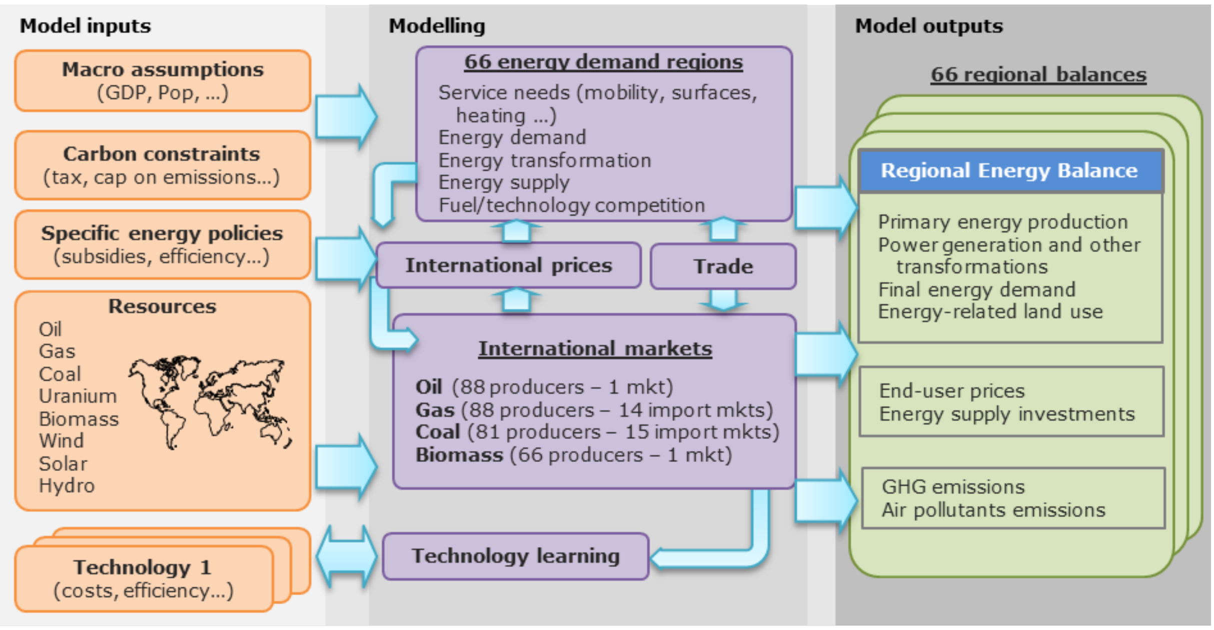
POLES-JRC covers the entire energy system, from primary supply (fossil fuels, renewables) to transformation (power, biofuels, hydrogen and hydrogen-derived fuels such as synfuels) and final sectoral demand (industry, buildings, transport). International markets and prices of energy fuels are calculated endogenously. Its high level of regional detail (66 countries & regions covering the world with full energy balances, including all detailed OECD and G20 countries) and sectoral description allows assessing a wide range of energy and climate policies in all regions within a consistent global frame: access to energy resources, taxation policy, energy efficiency, technological preferences, etc. POLES-JRC operates on a yearly basis up to 2100 and is updated yearly with recent information.

The POLES-JRC model applied for the CETO project is specifically enhanced and modified to capture learning effects of clean energy technologies.

POLES-JRC results are published within the series of yearly publications "Global Climate and Energy Outlooks" – GECO. The GECO reports along with detailed country energy and GHG balances and an on-line visualisation interface can be found at: https://joint-research-centre.ec.europa.eu/scientific-activities-z/geco_en

A detailed documentation of the POLES-JRC model is provided in (Després et al., 2018).

**Figure 49:** Schematic representation of the POLES-JRC model architecture.



*Source: POLES-JRC model*

### AN 3.2.2 POLES-JRC Model description

## Power system

The power system considers all relevant power generating technologies including fossil, nuclear and renewable power technologies. Each technology is modelled based on its current capacities and techno-economic characteristics. The evolution of cost and efficiencies are modelled through technology learning.

With regard to the power technologies covered by CETO, the model includes solar power (utility-scale and residential PV, concentrated solar power), wind power (on-shore and off-shore), hydropower and ocean power. Moreover, clean thermal power technologies are taken into account with steam turbines fuelled by biomass, biomass gasification, CCS power technologies and geothermal power. Furthermore, electricity storage technologies such as pumped hydropower storage and batteries are also included.

For solar and wind power, variable generation is considered by representative days with hourly profiles. For all renewables, regional resource potentials are considered.

*Electricity demand*
Electricity demand is calculated for all sectors taking into account hourly fluctuations through the use of representative days. Clean energy technologies using electricity consist of heat pumps (heating and cooling), batteries and fuel cells in transport, and electrolysers.

*Power system operation and planning*
Power system operation allocates generation by technology to each hour of representative days, ensuring that supplying and storage technologies meet overall demand, including grid imports and exports. Capacity planning considers the existing power mix, the expected evolution of electricity demand as well as the techno-economic characteristics of the power technologies.

## Hydrogen

POLES-JRC takes into account several hydrogen production routes: (i) low temperature electrolysers using power from dedicated solar. wind and nuclear plants as well as from the grid, (ii) steam reforming of natural gas (with and without CCS), (iii) gasification of coal and biomass (with and without CCS), (iv) pyrolysis of gas and biomass as well as (v) high temperature electrolysis using nuclear power.

Hydrogen is used as fuel in all sectors including industry, transport, power generation and as well as feedstock for the production of synfuels (gaseous and liquid synfuels) and ammonia. Moroever, hydrogen trade is modelled, considering hydrogen transport with various means (pipeline, ship, truck) and forms (pressurised, liquid, converted into ammonia).

## Bioenergy

POLES-JRC receives information on land use and agriculture through a soft-coupling with the GLOBIOM-G4M model (IIASA, 2024). This approach allows to model bioenergy demand and supply of biomass adequately by taking into account biomass-for-energy potential, production cost and reactivity to carbon pricing.

Biomass is used for power generation, hydrogen production and for the production of 1st and 2nd generation of liquid biofuels.

## Carbon Capture Utilization and Storage (CCUS)

POLES-JRC uses CCUS technologies in:

- Power generation: advanced coal using CCS, coal and biomass gasification with CCS, and gas combined cycle with CCS.
- Hydrogen production: Steam reforming with CCS, coal and biomass gasification with CCS, and gas and biomass pyrolysis.
- Direct air capture (DAC) where the $CO_2$ is either stored or used for the production of synfuels (gaseous or liquid).
- Steel and cement production in the industrial sector.
- Second generation biofuels production.

The deployment of CCS technologies considers region-specific geological storage potentials.

## Endogenous technology learning

The POLES-JRC model was enhanced to capture effects of learning of clean energy technologies. To capture these effects, a one-factor learning-by-doing (LBD) approach was applied to technologies and technology sub-components, aiming at endogenising the evolution of technology costs.

POLES-JRC considers historical statistics and assumptions on the evolution of cost and capacities of energy technologies until the most recent year available (this report: 2022/2023). Based on the year and a capacities threshold, the model switches from the default time series to the endogeneous modelling with the one-factor LBD approach. Within the LBD, the learning rate represents the percentage change of the cost of energy technology based on a doubling of the capacity of the energy technology.

This generic approach is applied on a component level to capture spillover effects as well. For instance, a gasifier unit is used as component for several power generating technologies (e.g. integrated gasification combined cycle, IGCC) as well as for several hydrogen production technologies (e.g. gasification of coal and biomass). Therefore, the component-based LBD approach allows to model spillover effects not only across technologies, but also across sectors. Also, it allows to estimate costs for emerging technologies for which historical experience does not yet exist.

Moreover, for each component a floor cost is specified which marks the minimum for the component's investment cost and serves as limitation for the cost reduction by endogenous learning. Cost reductions by learning in POLES-JRC slow down when the investment cost approaches the floor cost.

The described method above applies not only for the overnight investment cost of energy technologies, but as well for operation and maintenance (OM) costs, which also decrease as technologies improve, and for efficiencies. In the model, OM costs diminish synchronously to the decrease of total investment cost of the technology. The efficiency of renewables is implicitly taken into account in the investment cost learning and the considered renewable potentials. For most technologies the efficiencies are endogenously modelled.

### AN 3.2.3 Global CETO 2°C scenario 2024

The global scenario data presented in the CETO technology reports 2024 refers to a 2°C scenario modelled by the POLES-JRC model in a modified and enhanced version to address the specific issues relevant for the CETO project.

The *Global CETO 2°C scenario 2024* and its specific POLES-JRC model configuration is described in detail in the forthcoming report "*Impacts of enhanced learning for clean energy technologies on global energy system scenario*" (Schmitz et al., 2024).

The *Global CETO 2°C scenario 2024* is designed to limit global temperature increase to 2°C at the end of the century. It is driven by a single global carbon price for all regions that reduces emissions sufficiently so as to limit global warming to 2°C. This scenario is therefore a stylised representation of a pathway to the temperature targets. This scenario does not consider financial transfers between countries to implement mitigation measures. This is a simplified representation of an ideal case where strong international cooperation results in concerted effort to reduce emissions globally; it is not meant to replicate the result of announced targets and pledges, which differ greatly in ambition across countries.

As a starting point, for all regions, it considers already legislated energy and climate policies (as of June 2023), but climate policy pledges and targets formulated in Nationally Determined Contributions (NDCs) and Long-Term Strategies (LTSs) are not explicitly taken into account. In particular, the EU Fit for 55 and RePowerEU packages are included in the policy setup for the EU. Announced emissions targets for 2040 and 2050 for the EU are not considered.

The *Global CETO 2°C scenario 2024* differs fundamentally from the *Global CETO 2°C scenario 2023* used in the CETO technology reports in 2023 in various aspects[54]:

- The version of the POLES-JRC model used for the Global CETO 2°C scenario has been further enhanced and modified to capture effects of endogenous learning of clean energy technologies and, furthermore, several technology representations were further detailed, e.g. DAC (composition of renewable technologies, batteries and DAC unit), fuel conversion technologies (for hydrogen transport) and batteries in transport.

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[54] A description of the *Global CETO 2°C scenario 2023* can be found in Annex 3 of (Chatzipanagi et al., 2023).

- The techno-economic parameters have been thoroughly revised and updated taking into account the expertise of the authors of the CETO technology reports.

As a result, major scenario differences occur in the *Global CETO 2°C scenario 2024* regarding DAC, synfuels, CCS power technologies, wind power and ocean power.

### AN 3.3 Distinctions for the CETO 2024 Scenarios – POLES-JRC vs. POTEnCIA

The results of both models are driven by national as well as international techno-economic assumptions, fuel costs, as well as policy incentives such as carbon prices. However, on one side these two JRC energy system models differ in scope and level of detail, on the other side the definitions of the POTEnCIA and POLES-JRC scenarios presented in this document follow distinct logics, leading to different scenario results:

- The *Global CETO 2°C scenario 2024* (POLES-JRC) scenario is driven by a global carbon price trajectory to limit global warming to 2°C, where enacted climate policies are modelled, but long-term climate policy pledges and targets are not explicitly considered. Scenario results are presented for the global total until 2100.
- The *POTEnCIA CETO 2024 scenario* is a decarbonisation scenario that follows a trajectory for EU27's net GHG emissions aligned with the general objectives of the European Climate Law (ECL) taking into consideration many sector-specific pieces of legislation. Scenario results are presented for the EU27 until 2050.

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