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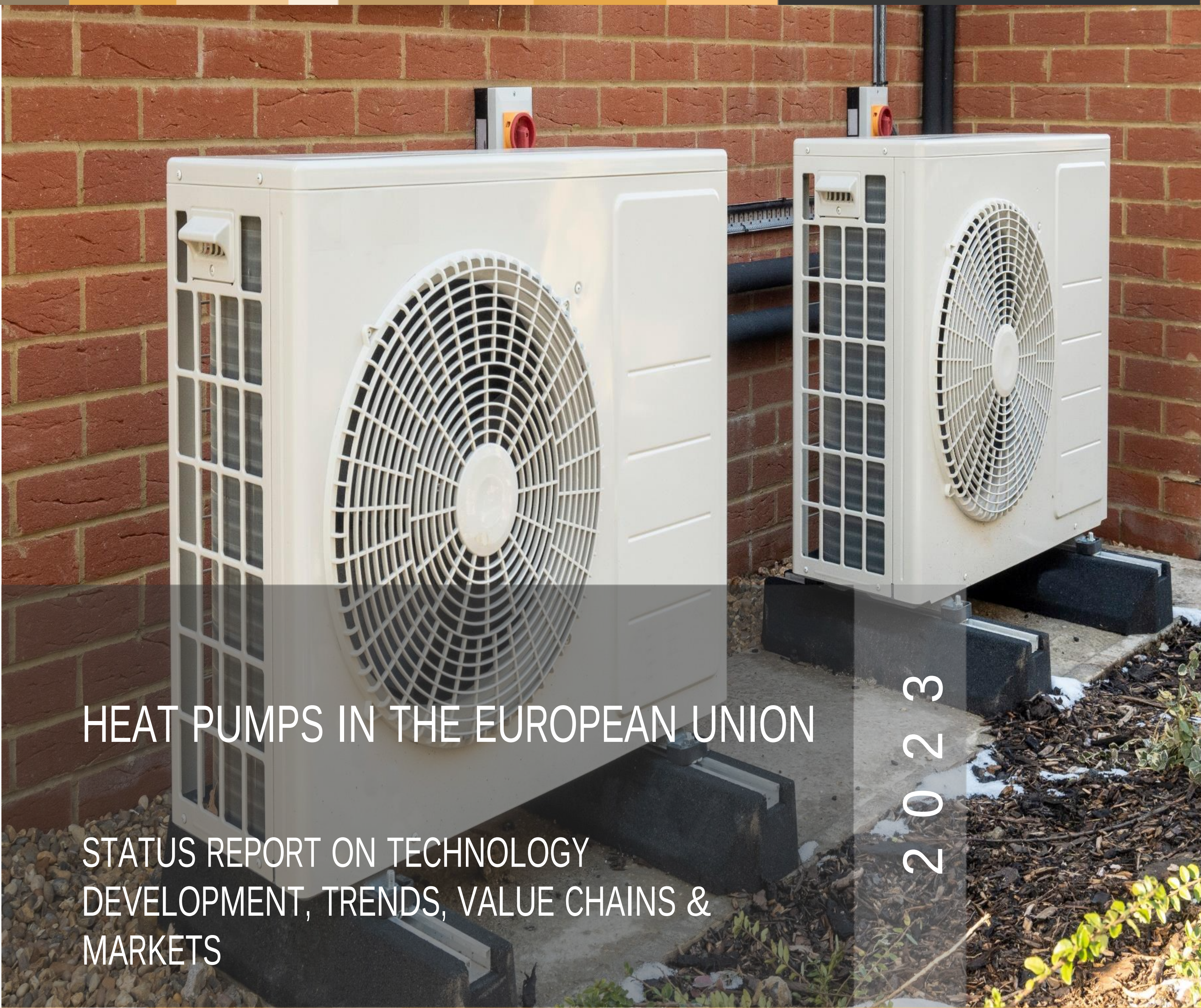

HEAT PUMPS IN THE EUROPEAN UNION

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

2023

Joint Research Centre

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Abstract

There are nearly 20 million heat pumps installed in Europe and deployment is proceeding apace, with sales of 3 million units in 2022. However, there are a number of barriers that might slow the rate of growth in the short term, including installer shortages, volatile metals prices, and disruptions to the supply of components such as semiconductors or permanent magnets.

Heat pump manufacturing in the EU is well positioned to capture a large share of the increase in demand, and might benefit from market and regulatory trends towards reduced environmental impacts. However, the trade deficit more than doubled to 856 million in 2022 compared to 2021, from a surplus of EUR 186 million five years earlier. Nevertheless, rapid deployment will entail increased EU manufacturing of heat pumps and components. Significant investments are already being made, totalling at least EUR 5 billion between 2020 and 2030.

Heat pumps are a mature technology but innovation continues, notably to improve efficiency and reduce up-front cost. The EU is a technology leader, especially in hydronic heat pumps and large heat pumps. This is reflected in patenting trends, scientific publications, and public RD&I funding.

This report is an output of the Clean Energy Technology Observatory, which is being implemented by the European Commission's Joint Research Centre on behalf of its DG Research and Innovation, in co-ordination with DG Energy.

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 serves as a primary source of data for the Commission's annual progress reports on competitiveness of clean energy technologies. It also supports the implementation of and development of 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]

[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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Executive Summary

This report is an output of the Clean Energy Technology Observatory, which is being implemented by the European Commission's Joint Research Centre on behalf of its DG Research and Innovation, in co-ordination with DG Energy. The scope is heat pumps for building applications, including large buildings and district heating and cooling (DHC) networks, and for industrial processes.

In the buildings context, heat pumps are used for heating, hot water, and in some cases (mainly in southern Europe) also for cooling. The most common types use electricity and the refrigeration cycle to concentrate and move heat. Heat pumps are much more energy efficient than boilers; enable the greater use of renewable energy sources, ambient or geothermal energy, and waste heat; and can increase the flexibility of the entire energy system.

In Europe, there were nearly 20 million individual heat pumps for heating and hot water installed by the end of 2022. Sales grew by around 39% in 2022, to more than 3 million.

Trends in production value and employment are positive as well, with about EUR 21 billion and 161 000 jobs. The EU heat pumps sector is well established and highly innovative. It is well positioned to benefit from increasing deployment, and from market trends such as the reduction of environmental impacts through Regulations on Ecodesign and F-gases (hydrofluorocarbon refrigerant supply is dominated by China).

In 2020 however, the EU trade balance turned from a surplus to a deficit for the first time, mainly as a result of growth in imports, in particular from China. The trade deficit more than doubled to 856 million in 2022 compared to 2021, from a surplus of EUR 186 million five years earlier. Imports from China doubled in 2021 to reach EUR 533 million and nearly doubled again to EUR 898 million in 2022.

Nevertheless, continued rapid deployment will require increased EU manufacturing of heat pumps and also some components. EU suppliers are already ramping up production, to maintain or grow their share of this rapidly growing market. Announced investments in new and extended factories, as well as repurposing of existing production lines, total about EUR 5 billion between 2020 and 2030. Long-term market predictability based on a stable policy framework will be key to maintaining this trend.

Public RD&I investment into heat pumps is increasing. Amounts are small compared to some other energy technologies, but significant relative to the rest of the world.

The EU is a technology leader, especially in hydronic heat pumps and heat pumps for large buildings, DHC networks and industrial applications. This is also reflected in private research investments, patenting and scientific publications.

Heat pumps have few specific materials vulnerabilities. They are however vulnerable to broader trends such as volatility in metals prices or disruption to the supply of components such as semiconductors and permanent magnets.

Table 1. SWOT analysis of the competitiveness of EU heat pump manufacturing

Strengths	Weaknesses
– Rapid sales growth (+39% in 2022, +34% in 2021) sustaining high revenues. – High market share of EU manufacturers (73%). – Relatively common raw materials; few heat pump-specific components; relatively straightforward assembly. Like other EU manufacturing sectors in terms of energy and resource consumption, processes, labour costs, etc. – No specific supply risk, high degree of component commonality with other products, and typical lifetime of 17 years. – Manufacturing sites in several Member States; mix of EU headquarters and local subsidiaries.	– In the short term, customers in several countries are experiencing delays. – General shortage of labour in the EU for both manufacturing and installation (gas boiler phaseout might help somewhat). – Beyond manufacturing, a general shortage in the EU of specialised profiles needed for installation and maintenance (e.g. plumbers, electricians, engineers, architects). Integration of heat pump-specific skills in curricula for such trades and better recognition of qualifications also needed.

– Very mature technology, no breakthroughs needed in short term; high activity in incremental innovation, e.g., cost, efficiency, size, noise, refrigerants. – Strong investment pipeline in EU manufacturing (EUR 4.8 billion assembly, EUR 1.1 billion components); on track to deliver projected sales in the medium term (i.e. 2030). – Renovation and construction work is highly local.	
Opportunities – Strong technological lead of EU companies. The EU is particularly strong in ground-source and large heat pumps, for which development of DHC represents an opportunity. – Experience of EU manufacturers with alternative refrigerants. The phaseout of F-gas refrigerants may represent an opportunity for the EU heat pump value chain overall in the medium term. Heat pumps avoiding these substances will also find markets outside the EU. – Early integration with smart grids would increase interoperability and benefits for users. – Entry of heat pump manufacturers from outside the EU could be a threat, but via acquisitions or creation of subsidiaries new entrants could also bring capital investment, innovation and economies of scale.	Threats – An increasing share of extra-EU imports is a threat for 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. – Longer term, the research activity of China and other third countries and regions in terms of patenting and publications could threaten the technological leadership of the EU.

Source: Adapted from EC, 2023.

1. Introduction

1.1 Scope and context

This report is an output of the Clean Energy Technology Observatory (CETO), which is being implemented by the European Commission's Joint Research Centre on behalf of its DG Research and Innovation, in co-ordination with DG Energy. CETO's objective is to provide an evidence-based analysis feeding the policymaking process and hence increase the effectiveness of research, development and innovation (RD&I) policies for clean energy technologies and solutions. It monitors EU RD&I activities on the clean energy technologies needed to deliver the European Green Deal, and assesses the competitiveness of the EU clean energy sector and its positioning in the global energy market.

This report on heat pumps is one of a series of annual reports on technologies released as part of CETO. Of particular relevance are last year's edition of this report (Lyons et al., 2022) and the report on Industrial and District Heat and Cold Management, and this year's report on novel thermal storage.

In buildings, heat pumps are used for space heating, hot water, and in some cases also for space cooling. The most common types use electricity and the refrigeration cycle to concentrate and move heat. This report therefore focuses primarily on electric heat pumps but there are also thermally driven (gas) heat pumps and hybrid systems commercially available, as well as other technologies at research stage. Heat pumps are much more energy efficient than boilers; enable the greater use of renewable energy sources, ambient or geothermal energy, and waste heat; and can increase the flexibility of the entire energy system.

Heat pumps are typically reversible, i.e. they can be used for both heating and cooling, either alternately or simultaneously. This report focuses on heat pumps used at least partly for space heating or hot water. Units that are used only for cooling are excluded where possible.

A rated capacity of less than 12 kW is the cut-off point for heat pumps covered under Ecodesign requirements for individual systems in the residential sector (Lot 10). However, the scope of this report also includes larger heat pumps for multi-dwelling (apartment) buildings and commercial (offices, retail) buildings, for which dedicated heat pumps are available – often from the same manufacturers as in the residential segment. Unless otherwise specified, data in this report refers to these individual heat pump systems.

The scope also includes heat pumps used in district heating and cooling (DHC) networks – whether in a centralised way or located in individual dwellings as part of 5th Generation DHC (also known as cold DHC due to the low temperature in the network).[4] Finally, this year the scope includes heat pumps used in industrial processes. Data for these categories is less complete; where available, we will specify as appropriate.

The scope excludes devices that use similar concepts for different purposes or in other settings. Heat pumps or heat pump concepts are also used in fridges (1.7 billion in operation worldwide), clothes dryers, for climate control in vehicles (and battery management in electric vehicles), and to heat swimming pools.

1.2 Methodology and data sources

The report has been written following the CETO methodology that addresses three principal aspects:

- Technology maturity status, development and trends;
- Value chain analysis;
- Global markets and EU positioning.

The main data sources include:

- Patents statistics, for patents filed on heat pumps and sub-technologies;
- Existing scientific overviews and compilations.

[4] See for example https://5gdhc.eu/5gdhc-in-short and www.eon.se/en_US/foeretag/ectogrid.

2 Technology status and development trends

Heat pump systems can be classified by heat source (air, ground or water) and whether they distribute heat using air (via fan coils or air ducts) or water (hydronic) piped to radiators or underfloor heating. Heat pumps are generally used for thermal comfort but can also be designed primarily for the production of domestic (sanitary) hot water.

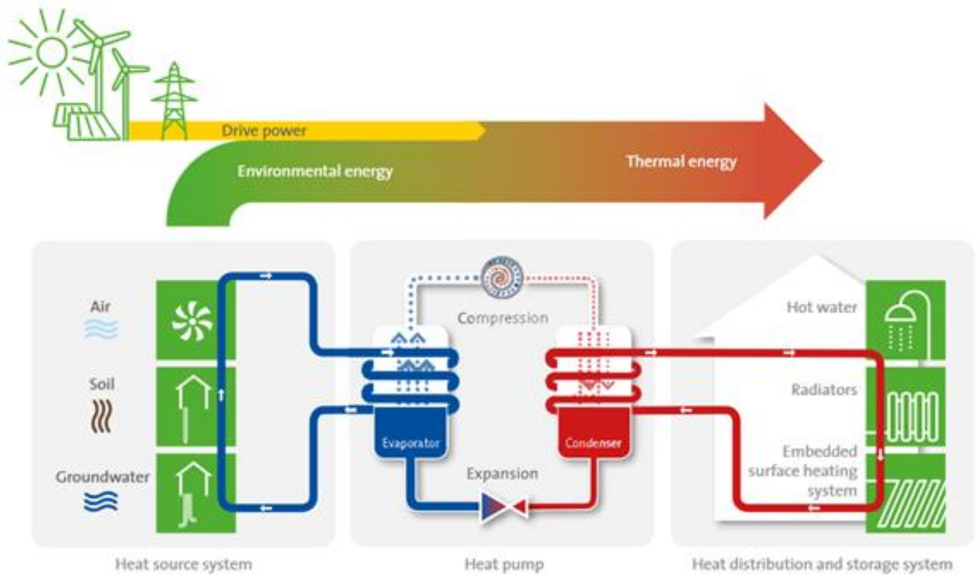
Electrically driven compressor heat pumps are by far the dominant technology in terms of sales and are the most efficient but other types are also commercially available, such as heat pumps that use gas instead of electricity, and hybrid heat pump systems that combine more than one technology. Adsorption heat pumps use solid sorption to capture ambient heat, while absorption heat pumps use a liquid.

A compression heat pump system is generally comprised of a) a heat source system, which could be an air fan 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 c) a heat distribution (and in some cases storage) system. There are various types of compressor available but most residential heat pumps use rotary or scroll compressors, depending on the capacity and operating range. Reversing valves change the flow of the refrigerant; thermostatic and electronic expansion valves regulate the flow.

Semiconductors are used in the controller but also in compressors, pumps and fans. Direct current (DC) inverters, DC pumps and DC fans all rely on printed circuit boards and semiconductors. Variable speed inverters allow the fan and compressor to run at different speeds depending on the demand, which is more efficient.

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 (Figure 1).

Figure 1. Working principle of a compression heat pump

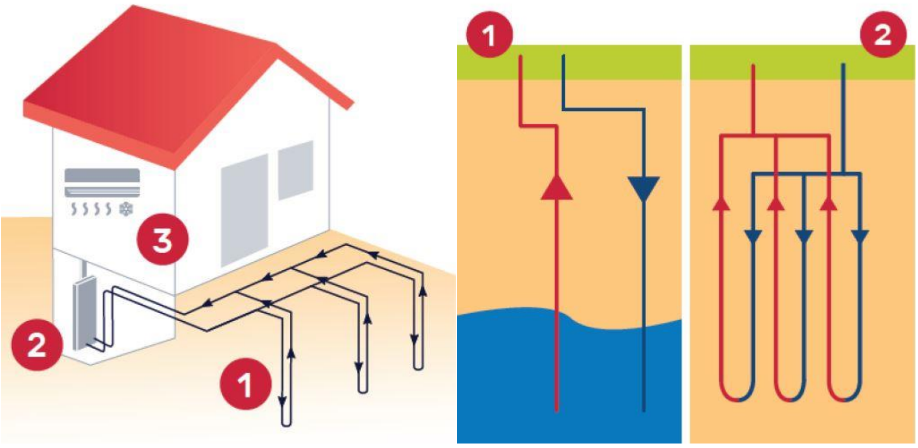


Source: EHI, 2021a.

All heat pump types can be used in a range of settings but each has distinct characteristics. For example, air-air heat pumps are often used in commercial buildings such as offices or hospitals due to building design and ventilation needs. They are attractive both in countries that have significant cooling demand (heat pumps dehumidify more efficiently than conventional air conditioners) and in cold countries such as Sweden, where they may suit open-plan layouts and combination with other heating systems such as biomass.

Ground-source heat pumps are also often used in larger buildings to take advantage of economies of scale and because they are particularly suitable for providing cooling and hot water as well as heating. They can use horizontal ground heat exchangers (loops) or boreholes (which require drilling), and they can be open loop or closed loop (Figure 2). As they don't require airflow, ground-source systems can be installed inside a home, ideally in a basement.

Figure 2. Illustration of a ground-source heat pump



Source: EGEC.

Notes: The left-hand image shows vertical closed loop collector (1), heat pump (2) and (3) distribution system. The right-hand image shows open loop (1) and closed loop (2) systems.

An exhaust air heat pump is a type of 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 often use ducting rather than radiators or underfloor heating. They can be particularly suitable for low-energy buildings.

Heat pumps generally have another technology acting as a back-up in case of failure, to meet peaks, or to take advantage of variable energy prices. 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).

A so-called hybrid system, on the other hand, is a heat pump combined with another technology, generally a gas boiler, as a supplementary heater (Box 1). Solar thermal can also be used, and photovoltaic-thermal (PV-T) collectors deliver both electricity and heat. 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 all hybrid systems.

Box 1. The outlook for hybrid heat pumps

Sales of hybrid heat pump systems are growing in a small number of European countries, notably Italy and the Netherlands (two countries that are relatively reliant on gas) as a result of supportive policy. Internationally, utilities in Quebec (Canada) are also promoting hybrids. Sales of such systems are expected to accelerate in those countries as a result, but there is debate among stakeholders about the role hybrid systems should play overall.

Advantages of hybrid heat pumps include potentially lower investment cost, higher life expectancy and smart operation. They can be deployed as an interim solution in buildings that are less well insulated. However, there is also a risk of emissions lock-in at building level if they use a gas boiler (as most do) and delay renovation; at macro level, they could delay the phaseout of fossil infrastructure and lead to unnecessary complexity in legal provisions, skills needs and distribution upgrades.

The extent to which deployment of hybrid heat pumps should be restricted to certain building categories will vary by country. One-stop shops might also help, by ensuring the most coherent balance between energy efficiency (e.g. insulation) and decarbonisation measures (e.g. heat pumps).

Heat pumps can also be integrated with rooftop PV, thermal storage (water tank, thermal mass or battery) and smart controls.[5] Such systems can maximise self-consumption and respond to electricity prices (Box 2). Further flexibility can be provided through cluster control or flexible operation of large heat pumps in DHC.

[5] See also this year's dedicated CETO reports on novel thermal energy storage and system integration.

Box 2. Digitalised and connected heat pumps

Heat pumps can be connected to storage in three ways: first, a water tank can store domestic hot water and a second tank can store heat or cold for later distribution; second, if equipped with floor or wall heating, the thermal mass of a building can be used to shift demand; third, a battery can be used to run the heat pump at night.

In the first two cases, the system provides a "thermal battery" to the grid: electricity is used in times of surplus to heat up the storage or building core. In times of shortage, the stored energy is distributed to maintain comfort. Heat pumps therefore provide load-shaping and load-shifting services. In the third case, a battery increases the independence of the system. While battery storage is still expensive, costs are rapidly coming down.

A heat pump system with thermal and battery storage (or using the thermal mass of the building itself) can provide heating and cooling for several hours or even a few days without needing grid electricity. This helps move demand off peak, and would be cheaper than maintaining reserve power plants or building new power generation and distribution infrastructure.

New market actors like Octopus, Tiko and OVO are already using heat pumps to provide grid flexibility in this way. Swiss start-up Tiko provides smart home energy systems in France and Germany, aggregating refrigerators, heat pumps and other electrical appliances to make Europe's largest virtual power plant. Its digital platform controls these appliances to shift or reduce peak demand, selling balancing power to the grid and reducing user bills. In addition, the platform couples appliances with private electricity generation such as rooftop PV to reduce bills even further. Similarly on that last aspect, inverter manufacturer SMA Solar Technology offers an energy manager that maximises the use of self-produced PV electricity with Stiebel Eltron (Germany) and Vaillant heat pumps.

Digitalisation is essential to enable such flexibility. It can also be used to improve maintenance: Ziehl-Abegg (Germany) offers cloud-based fan monitoring and predictive maintenance, while the Trecobat smart home app developed in France allows a heat pump to send an alert whereby the customer receives either a tutorial or an appointment for a technician to intervene.

Digitalisation also enables new business models. Suntherm in Denmark, for example, combines some of the above elements to provide heat pumps with no upfront cost. Its cloud-based system remotely controls the heat pumps, optimising their operation based on heating needs, consumption patterns and weather forecasts. Suntherm provides all maintenance and repairs and can also connect solar PV. Consumers pay for the services monthly over ten years.

These developments are spurring RD&I in both components and software. Digitalised heat pumps need sensors for temperature data, access to weather data (in particular solar irradiation), electricity price signals, intelligent controls that can understand the thermal behaviour of the building and user comfort requirements; and smart controls that can use all that data to optimise the service.

In additional to individual heating systems, digitalisation of DHC is an important area of activity in its own right. There is an active International Energy Agency (IEA) Technology Collaboration Programme (TCP) and EU-funded projects such as FLEXYNETS (intelligent DHC networks where substations are replaced with heat pumps and the network acts as low-temperature storage). Digitalisation can also speed up the identification and repair of leaks.

Combining central and decentralised heat pumps with energy grids and storage will provide flexibility and stability to the electricity grid in the most efficient manner. The EU project HEAT4COOL demonstrates integrated solutions complemented by heat pumps and renewable energy sources at building and district scales. It includes an online design tool that combines a set of technological solutions with data from real buildings to predict the performance of a variety of retrofit solutions.

Sources: Lyons, 2019; IRENA, 2023a; REN21, 2022.

The compressors and housing of heat pumps are made from reinforced steel. Heat exchangers are made from low-alloyed steel (for a plate heat exchanger), copper or aluminium. Piping can be made of steel, copper or aluminium depending on the refrigerant used, and welded using silver. Electrical cables and expansion valves use copper. Pipework is insulated with an elastomer and cables are insulated with vinyl chloride (PVC).

Refrigerants for compression heat pumps can be synthetically produced fluorinated gases (F-gases) such as R410A, which has a 100-year Global Warming Potential (GWP) of 2 088, R134a (GWP 1 300) or more recently R32 (GWP 675) as well as some hydrofluoroolefin options; or naturally occurring refrigerants such as R717 (ammonia, GWP 0.1), water, methanol, R744 (carbon dioxide, GWP 1) or R290 (propane, GWP 0.02).[6]

R410A accounts for the large majority of air-water and water-source heat pump sales in Europe currently, while most air-air heat pumps on sale use R32. Until now, compression heat pumps have generally used F-gases, but a shift to natural refrigerants where possible is under way, as a result of industry implementing the F-Gas Regulation (EC, 2022a) (Box 3).

Box 3. F-gases and heat pumps

F-gases made up 2.3% of total EU greenhouse gas emissions in 2019 (EEA, 2021). Driven by EU regulation, there is a move away from F-gases with high GWPs to natural refrigerants and F-gases with lower GWPs.

Under the F-Gas Regulation, the main measure to avoid the use of such gases in equipment such as heat pumps is a quota system that progressively limits the amount (in CO_2-equivalents) of hydrofluorocarbons (HFCs) that can be put on the EU market each year. A recent agreement to future-proof the Regulation increases the ambition of the quota system and adds relevant prohibitions. From 2027, most heat pumps of up to 12 kW capacity will only be able to use HFCs and other listed F-gases that have a GWP of less than 150.

Both the deployment of heat pumps and the phase-down of F-gases reduce greenhouse gas emissions, so it is important that these parallel trends are not in conflict. Some manufacturers argue that this more rapid phase-down will hamper the deployment of heat pumps (see for example EHPA, 2022). Others contend that the transition to more flammable substances presents significant additional complexities for compliance and building codes.

The issue seems mainly to lie with air-air heat pumps rather than hydronic ones, more in the short term than the medium term, and more to do with manufacturing capacity than technology. Yet the Commission proposal for a revision was designed to allow for the heat pump growth needed under REPowerEU and to allow sufficient time for manufacturers to adapt, while preventing direct emissions from refrigerants from increasing.

Production lines are already being converted, and new ones added, to focus on natural refrigerants. Experts co-ordinated by ATMOsphere (2023a) make the comparison with refrigerator manufacturers, who were able to make a similar switch within a timeframe of 3-5 years during the 1990s.

The cost to end users need not necessarily increase as a result of the phase-down, as they will also save energy. And in the unlikely event of the emergence of a major HFC market disruption (which did not occur in the first seven years, 2015-2022, of the quota system), the proposed Regulation included the possibility for the Commission to exempt a relevant sector or adjust the quota allocation mechanisms. The efforts to reduce the climate impact of refrigerants are therefore fully coherent with the faster roll-out of heat pumps.

A more ambitious HFC phase-down also helps the EU to reduce its reliance on imported refrigerants since HFCs are mainly imported (both legally and illegally). China is the leading producer of HFCs worldwide, and has nearly 60% of the production of fluorspar (calcium fluoride). In the EU, Bulgaria and Spain combined account for about 5% (Cheng and Lauly, 2022).

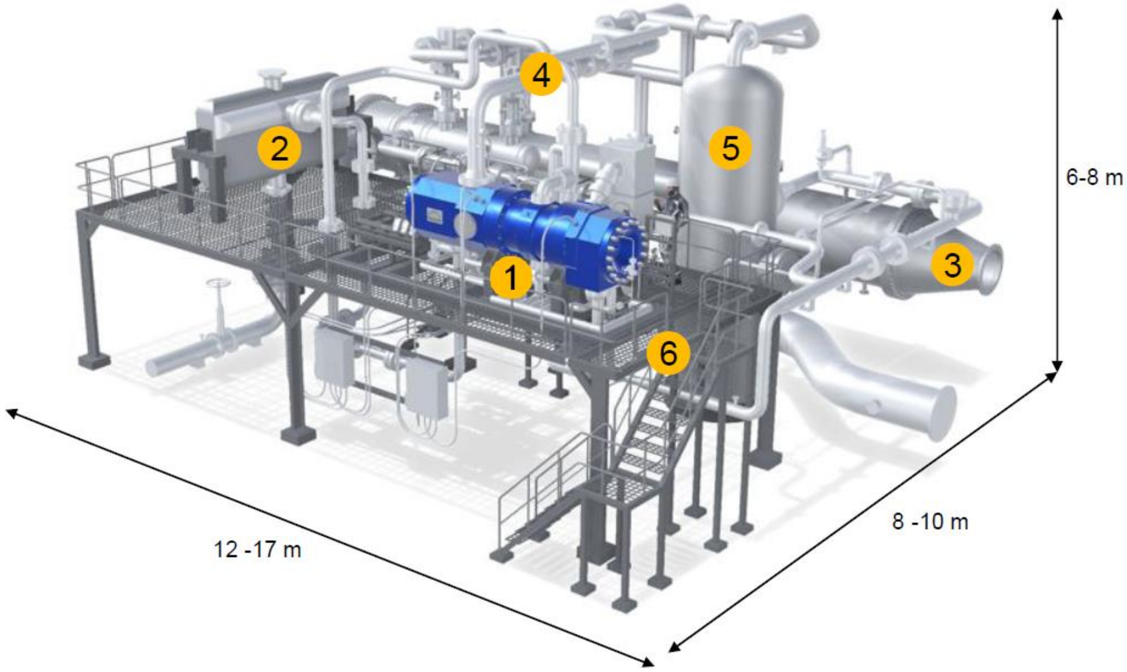
A shift to natural refrigerants (for well-justified environmental reasons) can thus represent an indirect market opportunity and area for innovation. EU companies have a head start in the design and manufacture of heat pumps using such refrigerants. Natural refrigerants may also have an advantage in terms of price trend and price stability, and they are not patented.

Source: JRC based on exchanges with DG CLIMA and others.

The working principle of a large heat pump for industry or DHC (Figure 3) is similar to that of smaller ones, with a heat source (water, air, flue gases, solar heat), evaporator, compressor (mainly piston, screw or turbo), condenser and lamination valve. The housing or casing of a smaller heat pump is replaced by a support structure and the room or building itself. Importantly, in an industrial setting there can be multiple heat sources (ambient energy, cooling tower, exhaust heat, etc.) and sinks (e.g. space heating, drying, process heat), taking advantage of the cascade effect.

[6] See also EC Report https://ec.europa.eu/clima/document/download/344eede6-497a-46b6-8151-91174d0f7eb9_en?filename=c_2020_6637_en.pdf.

Figure 3. Layout of a heat pump for district heating



Source: MAN Heat Pump – DBDH, 2023.
Notes: 1 = Compressor. 2 = Condenser. 3 = Evaporator. 4 = Piping and valves. 5 = Refrigerant tank. 6 = Steel structure.

The materials used in large heat pumps are broadly similar to those of smaller heat pumps, with a few exceptions, e.g. titanium is used in some heat exchangers. Both synthetic and natural refrigerants are available for high-temperature heat pumps up to 150°C.[7] Such heat pumps often operate with ammonia, carbon dioxide (CO_2) or hydrocarbons.

2.1 Technology readiness level

The main heat pump technologies are mature, with a Technology Readiness Level (TRL) of 9 (Table 2). There are also promising technologies at lower TRLs. Note that development status in practice depends on TRL but also other factors such as efficiency (Box 4), cost and availability.

Although heat pumps can be installed in almost all buildings, they work best in those with high energy performance and therefore low feed-in temperature requirements (less than 55°C). 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.

Advanced inverter designs can be driven at higher speed, and active variable heat exchangers can optimise performance when switching from heating to cooling functions. Microgroove copper tubes increase efficiency and reduce refrigerant volume.

Digital technologies can also help optimise performance, for example based on energy prices or weather (see Box 2 above). In this case, heat pumps can also leverage research from the broader digital and buildings sectors.

[7] In this report, high-temperature heat pumps generally refers to heat pumps in an industrial setting. In a residential setting, it can also refer to heat pumps that allow higher condensation temperatures. For example, current propane heat pumps can deliver temperatures of more than 60°C and CO_2 is promising for operating temperatures up to 80°C.

Box 4. Energy efficiency of heat pumps

The efficiency of a heat pump, expressed in Coefficient of Performance (COP), is the ratio of useful heat output to the electricity input for operation. Likewise in cooling mode, efficiency is described by the energy efficiency ratio (EER), which is the ratio of cooling provided relative to the amount of electrical input required.

While the COP is usually based on lab measurements in standard conditions, the seasonal COP (SCOP) gives a realistic indication of energy efficiency over an entire year and is calculated for a given climatic zone (e.g. northern Europe, central Europe and southern Europe). In addition, the Seasonal Performance Factor (SPF) is measured for a given heat pump over one year and depends on the building concerned. The current threshold for a “renewable” heat pump system under the RED is an SPF of at least 2.5.

The Ecodesign Regulation now uses SCOP, which ranges from 2.8 to 6.2, depending on the type of heat pump, the model, the refrigerant used, and the services being provided (heating, cooling or hot water). There is potential for further performance increase for most heat pump models.

Examples of SCOPs for air conditioners (in heating mode) can be found on the European Product Registry for Energy Labelling (EPREL) website. The COP of large heat pumps used in DHC is usually between 1.7 and 3.8 (Tilia et al., 2021). Under the EU Taxonomy, heat pumps must meet the energy efficiency requirements under Ecodesign.

Performance deterioration can occur in the absence of maintenance (EHI, 2021b). This deterioration could be as much as 20% from the second year onwards, with one industry association in France claiming that 50% of heat pumps are not being maintained (lebatimentperformant.fr, 2023). It is also important to consider factors such as poor installation, design and usability (in particular of smart controls), as well as potential rebound effects (Alfieri and Spiliotopoulos, 2023).

Other 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, encapsulation or new designs; industrial, large building, and DHC applications (see below); 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). Reversible heat pumps also make DHC networks more efficient and profitable because they can provide services (heating and cooling) 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.[8]

Designs of hydrocarbon heat pumps from about 48 different manufacturers are commercially available in Europe (ATMOsphere, 2023a). The basic RD&I to optimise heat exchangers and compressors to use low-GWP refrigerant has been done but research is still needed in order to ensure safe end-of-life disposal and to comply with the F-Gas Regulation.[9]

More innovative types of heat pump are 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.[10]

[8] 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.
[9] See for example www.ise.fraunhofer.de/en/research-projects/lc-150.html.
[10] RES4BUILD (https://res4build.eu/) is one Horizon 2020 project looking to improve the performance of magnetocaloric heat pumps.

- Thermo-acoustic heat pumps work by compressing and expanding helium, and could use 20% less electricity; also for industrial applications.[11]
- 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 prototype stage.

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).*

At EU level, the framework for technology development is set by the implementation plans of the Strategic Energy Technology Plan (SET-Plan) working group on energy efficiency in buildings and the Strategic Research and Innovation Agenda of the European Technology and Innovation Platform on Renewable Heating and Cooling (RHC Platform). The SET-Plan working group has specific targets for heat pumps to:

- 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.[12]

The RHC Platform updated its Strategic Research and Innovation Agenda in 2021. It contains a comprehensive list of research priorities and topics for the heat pumps sector, grouped under: Demand from the end user perspective; Design; Manufacturing; Installation; Maintenance and operation; and Replacement and upgrading (RHC Platform, 2021).

[11] See for example www.blueheartenergy.com or www.equium.fr.
[12] See https://setis.ec.europa.eu/implementing-actions/energy-efficiency-buildings_en.

Several Member States are also members of the IEA TCP on Heat Pumping Technologies.[13] 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.

2.2 Industry and district heat

Heat is responsible for 60% of energy consumption in the industry sector (EC, 2020). But industry includes diverse sub-sectors, ranging from ones that need very high temperatures supplied directly to the process (steel, cement, glass and non-ferrous metals) to sectors that use direct heat and steam (chemicals) to lower temperature sectors where heat is mainly delivered to the process via steam (pulp and paper, food and drinks). This diversity means that deep 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 principle 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.

Installations are mostly bespoke, as industrial heat pumps need to be adapted to the local conditions. This makes it easier to install an industrial heat pump at a new site than to retrofit. In terms of capacity, they can be factory-built and modular from 100 kW to 1 MW, tailor-made from 1 MW to 10 MW, and large scale heat pumps exist from 10 MW to 100 MW (Arpagaus, 2023).

Industrial heat pumps are still small in number relative to the market potential. However, demand is increasing, notably in food and materials drying,[14] distilling, dairy production (pasteurisation) and paper. They are a cost-effective and innovative way to reduce energy consumption and related emissions, among multiple benefits such as production increases and employee upskilling.

The industrial heat pumps market would benefit from more standardised components, in particular compressors and heat exchangers,[15] a boost in manufacturing capacity, as well as communications to raise awareness of the feasibility and opportunities. Improved market data would also help, and CETO and the forthcoming Heat Pump Action Plan could play a role in that regard.

In the DHC sector, the opportunity for heat pumps (and waste heat recovery) is increasing as network temperatures are lowered in 4th generation DHC. Lower temperatures with large heat pumps allow the integration of new sources such as geothermal, solar thermal, and waste heat from sewage, metros, data centres, supermarkets or public buildings such as hospitals. Research challenges include optimisation of temperature and flow, optimal network design, resilience, reduction of losses, new business models, and provision of flexibility in combination with thermal storage and electric boilers.

High-temperature heat pumps with supply temperatures up to 160°C are commercially available, though performance and cost need to be improved further. Prototypes are being tested up to 200°C[16] and ongoing research shows viability up to 280°C (Zuehlsdorf et al., 2019). Upgrade to 400°C is being researched at TRL 3-4 but is not yet economically viable (EC, 2020). Subject to changes in policy or economic conditions, it is expected that various high-temperature heat pump technologies will become commercially available and implemented in 2024 or 2025 for supply at up to 120°C, 2025 or 2026 for temperatures up to 160°C, and 2026 to 2027 for even higher temperatures (IEA HPT, 2023).

[13] Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands and Sweden.
[14] See for example the DryFiciency project, https://dryficiency.eu, in starch, brick and waste treatment processes.
[15] See for example the compressor developed at Smurfitt Kappa in the Czech Republic as part of the EU-funded Spirit project: https://spirit-heat.eu/demo_sites/corrugated-packaging-production.
[16] See for example the Danish project, www.suprheat.dk.

2.3 Installed capacity and production

2.3.1 Units

Current situation

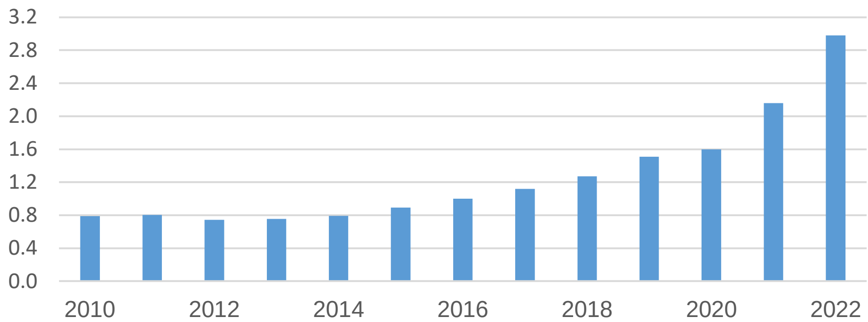
There were 58 million heat pumps installed in 2020 worldwide (IRENA, 2023b). The world heat pump market grew at an average rate of 10% per year between 2014 and 2020 to around 8 million units. Sales fell 3% in 2020 due to the pandemic (REN21, 2022) but rose by 11% in 2022. Sales of air-water heat pumps in China grew by 12.6% in 2021 to around 2.2 million units (JARN, 2022). The US heat pump market has also been growing steadily, and annual heat pump sales (mostly air-air) have exceeded gas boiler sales since 2020 (Malhotra et al., 2023).

In Europe,[17] there were almost 20 million heat pumps installed by the end of 2022,[18] according to EHPA data.[19] In other words, Europe accounts for about 34% of all heat pumps, compared to about 15% of world GDP and 10% of world population.

Nevertheless, there are still 68 million gas boilers and 18 million oil boilers installed in the EU (Toleikyte et al., 2023). Also, the stock of heat pumps is not evenly spread by Member State, with colder Member States (Sweden, Finland, Estonia) having more heat pumps per capita. Ground-source heat pumps in particular are concentrated in key markets such as Sweden (more than 600 000 installed) and Germany (more than 400 000), which together account for half of installed ground-source heat pumps in Europe, according to the European Geothermal Energy Council (EGEC).

Sales have been growing fast (Figure 4): 1.62 million units were sold in Europe in 2020.[20] Sales grew by around 34% in 2021, and by 39% in 2022 to more than 3 million (2.75 million in the 18 Member States covered). About 90% of those sales were for space heating, with the rest for hot water. Belgium, Czech Republic, Slovakia and Poland nearly doubled heat pump sales in 2022 (EHPA, 2023a).

Figure 4. Heat pump sales in Europe, 2010-2022 (millions)

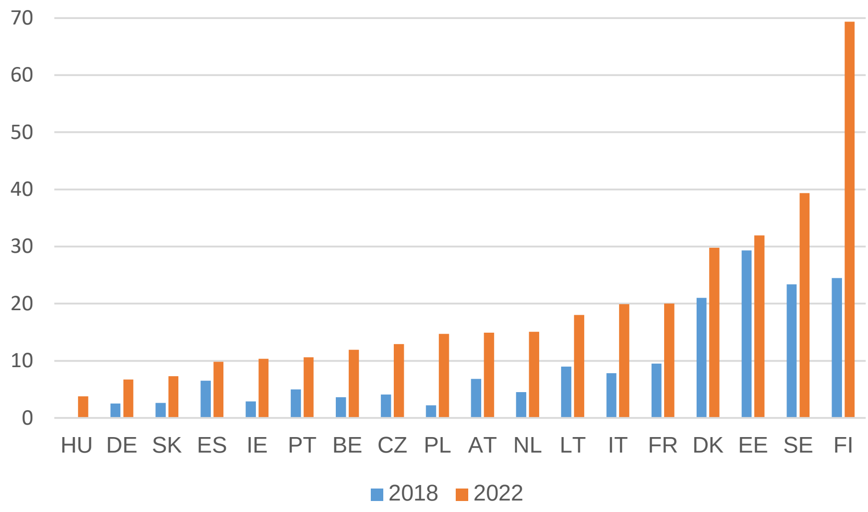


Source: Based on EHPA data.

In 2022, Finland saw 69.36 heat pumps sold per thousand households (Figure 5). Hungary sold the least relative to its size among the Member States for which there is data, at 3.77 heat pumps per thousand households – though that is 54 times the level of 2018. Sales per household more than doubled between 2018 and 2022 in all but four countries: Spain, Denmark, Estonia and Sweden. The overall share of European residential and commercial buildings with a heat pump installed is about 16% (EHPA, 2023a).

[17] EHPA data cover 21 European countries: 18 Member States, the UK, Norway and Switzerland. Bulgaria, Cyprus, Greece, Croatia, Latvia, Luxembourg, Malta, Romania and Slovenia are not included.
[18] EHPA stock data assumes a lifetime of 20 years.
[19] The use of air-air heat pumps predominantly for heating is assumed for countries in cold climates (Estonia, Denmark, Finland, Lithuania, Norway). The number of units reported results from total sales adjusted by a correction factor (around 10%) aiming to exclude cooling-only units. In the case of Sweden, where air-air sales data is no longer collected by the national association, the number of air-air units was estimated by EHPA. Air-air units sold in the average climate zone have not been counted, due to a lack of reliable information on their use for heating or cooling. For countries in the warm climate zone (France, Italy, Portugal and Spain) only a share of the total sales number has been included. A study of the Italian market comes to the conclusion that in 9.5% of all dwellings, reversible air-air heat pumps were the only heat generator installed. This value is used for Italy with a similar assumption being taken for Portugal, Spain and southern France. Reversible heat pumps connected to hydronic systems are always counted, as their primary use as heating system can be assumed. Multi-split systems are counted, as they are specifically designed for heating and cooling. 90% of the reported sales numbers are included in order to allow for deviations from declared use (i.e. used for cooling only).
[20] Sales data refer to heat pumps sold to installers and distributors, not to the amount received by end users. Some heat pumps ordered in 2022 are now in inventory.

Figure 5. Heat pump sales per thousand households, 2022



Source: Based on EHPA data.

Heat pump sales in Germany were 122% higher in Q12023 than in Q12022 (BDH/BWP cited by EGEC) but appear to have moderated since then. In some other countries, e.g. Italy and Finland, sales in the first half of 2023 even decreased compared to the first half of 2022 (EHPA, 2023b). This trend is both a "sugar crash" due to policy changes to national support schemes, and a result of unfavourable electricity-gas price ratios.

Existing buildings need to be assessed for energy performance but in many cases heat pumps can be deployed even without renovation, either standalone or as part of hybrid systems. In Germany, about half of new buildings in 2021 used heat pumps (Destatis, 2023). In Finland the share is 70-80% (Schwartzkopff, 2022), but renovation already accounts for 92% of heat pump sales. Italy (85%) and Spain (75%) also show high shares of existing buildings in total sales (EHPA, 2021a). In Sweden, more than half of single-family homes have a heat pump installed (REN21, 2022), with 95% of new builds heated by heat pumps.

The market for air-water heat pumps, which are mainly used for heating, grew particularly fast in Poland (108% growth), Denmark (51%), Germany (44%), Belgium (36%) and Sweden (34%), driven by strong policy incentives in those countries. In Hungary, the air-water heat pump market exploded from virtually non-existent to more than 5 000 units sold in 2020 (JRC, 2021).

For ground-source heat pumps, sales were 110 000 in Europe in 2022. Germany saw 31 000 units sold, according to EGEC – a 14% increase compared to 2021. Germany and Sweden still account for nearly half of annual sales, but growth was even stronger in Finland (24%). The biggest markets for air-air heat pumps are still Italy, Spain and France.

Heat pumps for the production of domestic (sanitary) hot water are used mainly in China (1.27 million units sold in 2021) and Japan (585 000 units). In the EU, France dominates sales, with 163 125 heat pump water heaters sold in 2022, out of a total of around 320 000 (EHPA, 2023a). The hot water heat pumps segment grew particularly fast over the past decade, often in combination with a fossil fuel boiler or PV system (EHPA, 2021b). France is also the largest market in the EU for PV-T systems used as the heat source for heat pumps (REN21, 2022).

Electric heat pumps represent more than 95% of sales in Europe by type. Hybrid sales were at 17 000 in 2022 (EHPA, 2023a), with the stock of thermally driven heat pumps in Europe also in the tens of thousands, installed in the light commercial sector in particular.

The heat pump market share of larger heat pumps for multi-family (apartment) buildings in Europe is relatively small. Less than 10% of heat pumps sold have a capacity of more than 20 kW (EHPA in Toleikyte et al., 2023), though there are also projects with individual small systems for each apartment.[21] Sales of DHC heat pumps were 6 000 in 2020 (EHPA, 2021a).

There were less than one million heat pumps in industry installed worldwide in 2020 (IRENA, 2023a). Sales of industrial heat pumps in Europe in 2022 were 2 618 (EHPA, 2023a), up from 602 in 2016 (BNEF in EC, 2020).

[21] For more information and case studies, see www.ehpa.org/heat-pumps-and-high-rise-homes-case-studies-from-across-europe.

The United States, Japan and China are also important and growing markets; Japan had more than 6 000 systems installed by 2020 (Kaida et al., 2023).

Projections

Worldwide, the 1.5°C Scenario of IRENA will require 793 million heat pumps in operation by 2050 (IRENA, 2023b). The EU market is projected to account for 20-30% of the world heat pumps market during 2020-2030 (Keramidas et al., 2022).

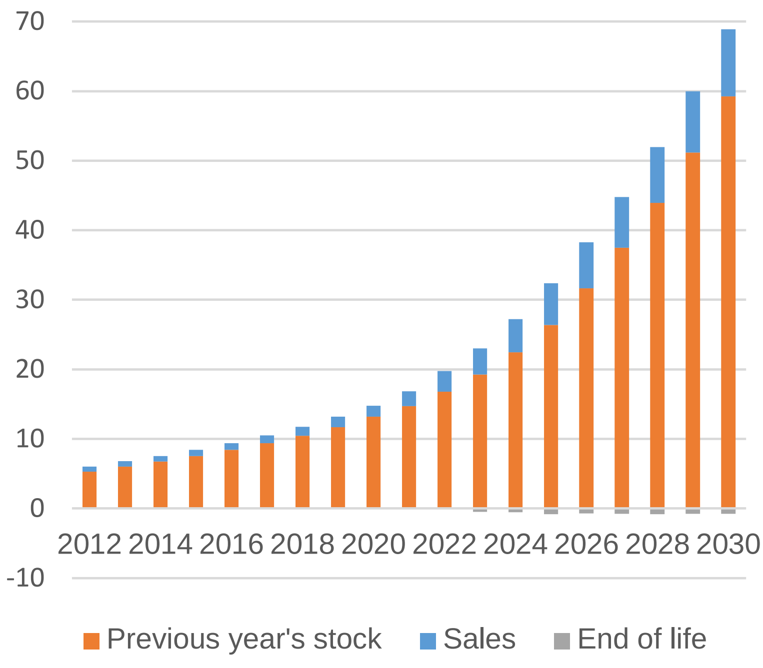
In May 2022, the European Commission presented the REPowerEU Plan (EC, 2022b) to make Europe independent from Russian fossil fuels by 2030, including through the accelerated deployment of heat pumps and an increased role for heat pumps in DHC. REPowerEU also acknowledged the need to match faster deployment with the scale-up of European manufacturing, greater resilience and enhanced competitiveness.

The slow pace of renovation in Europe is less of a barrier than in the past, thanks to improvements in heat pump technology and an expected increase in retrofit rate under the Renovation Wave. About one third of the dwellings with fossil boilers that will need to switch to a heat pump under REPowerEU can do so without major alterations to the building envelope or heating system (Toleikyte et al., 2023).

A Heat Pump Action Plan is set to be adopted soon. It will be a policy document with specific actions to address barriers to deployment such as skills shortages.

The average growth rate in sales between 2020 and 2022 (27%) can be expected to moderate over time (see previous section), towards 10% annually in 2030 (Mitsui & Co., 2023). In that case, and assuming a heat pump lifespan of 17 years, there would still be a cumulative stock increase of around 25 million units over the period 2022-2027 and 50 million units over 2022-2030, to reach almost 70 million units in operation (Figure 6). This implies that REPowerEU is on track in the short term but there are a number of challenges to be overcome in order to maintain that growth and prolong it beyond 2030.

Figure 6. Heat pump stock model, 2012-2030



Source: EHPA historical data and JRC projection based on a lifespan of 17 years.

By 2050, the outlook is even more uncertain but as the market matures and a greater share of sales are replacing existing heat pumps rather than boilers, the stock could reach 117 million units in operation around Europe, with sales stabilising at around 4 million per year.

In the long term, individual heat pumps should supply the majority of demand in low heat-density areas (typically detached houses outside towns and cities) (HRE, 2018). However, heat pumps are also increasingly used in DHC. DHC has a particular advantage in very dense areas where external units may be difficult to install.

The Heat Pump Action Plan will also address industrial heat pumps. Under the 1.5°C scenario of the International Renewable Energy Agency (IRENA), there would be 35 million heat pumps installed in industry installed worldwide by 2030, and 80 million by 2050 (IRENA, 2023a). In Europe, if an industrial heat pump market could be established to capture 5% of the total potential, the market rollout would be 37 TWh per year (de Boer et al., 2020).

2.3.2 Capacity

Current situation

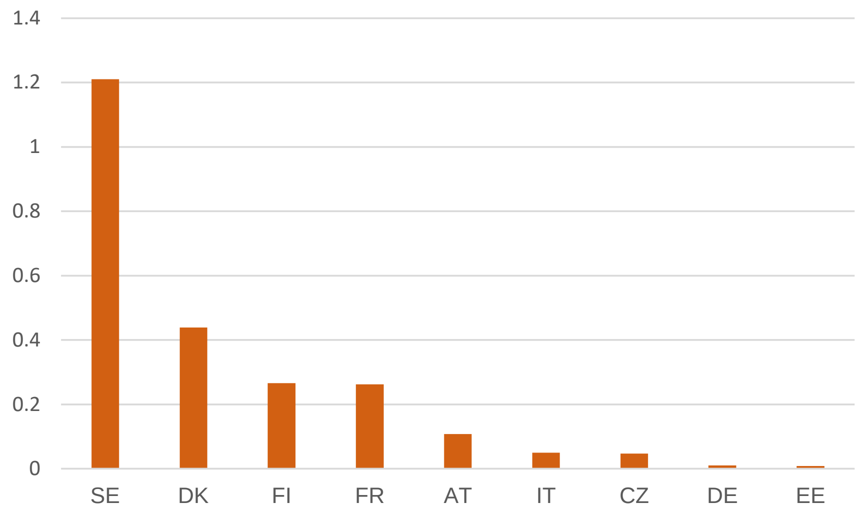
Heat pumps in single-family dwellings are in the range 3-23 kW thermal capacity, with an average of 10-11 kW according to VHK and BRG (2019). Air-air heat pumps are often of small capacity, less than 5 kW. Air-water and ground-source heat pumps are more often in the 5-20 kW range. In ground-source heat pumps, the average capacity is increasing according to EGEC, i.e. more units are providing heating, cooling and water for large buildings. Heat pumps tend to be oversized by 10-20%, further enabling the kind of storage options mentioned in Box 2.

Heat pumps for multi-family buildings have capacities of more than 20 kW but account for less than 10% of all heat pumps sold (EHPA, 2023a). Light commercial heat pumps can have capacities up to several 100 kW, while those for use in DHC range from 300 kW to 160 MW (Lyons et al., 2021).

Based on the IRENA estimate of installed units and assuming an average capacity of 7.5 kW, there was 435 GW of heat pump capacity worldwide in 2020. The installed stock in Europe was around 129 GW, or 30%. In 2022, heat pumps with a thermal capacity of 28.18 GW were installed in Europe (EHPA, 2023a).

Large heat pumps represented an installed capacity of 2.4 GW in DHC networks in the EU in 2021 (EH&P, 2022) (Figure 7). That is only around 1% of total DHC capacity, and 2% of the heat pump capacity serving individual dwellings. A 2016 estimate had put the capacity at 1.6 GW however, so it has been growing strongly, and significant potential remains (see next section).

Figure 7. Installed capacity of large heat pumps in district heating and cooling networks by Member State, 2021 (GW)



Source: Based on EH&P data.

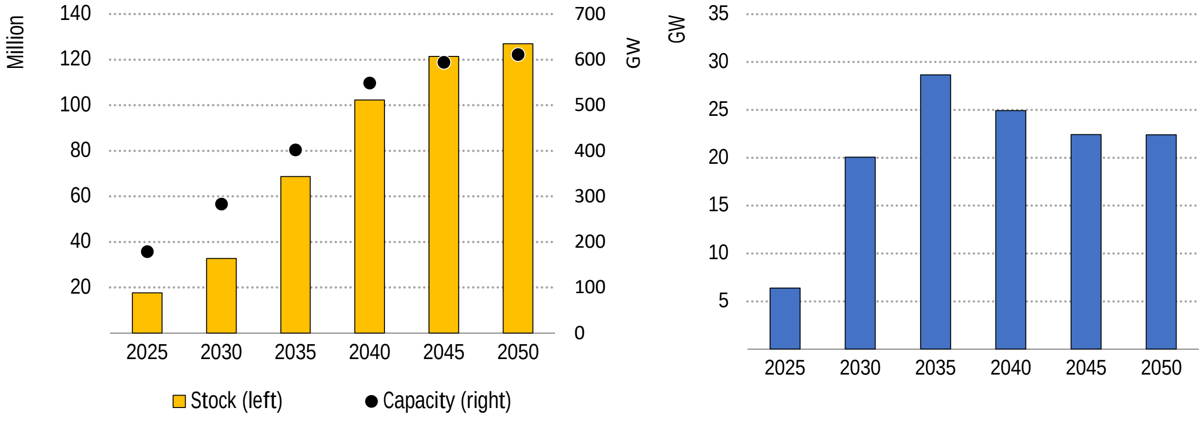
In terms of energy consumption, heat pumps met around 7% of world heating demand in residential buildings in 2020 (REN21, 2022). In the EU, the share is around 10%, which is a five-fold increase since 2009.

Projections

The thermal capacity of heat pumps installed worldwide would need to grow to 4 917 GW by 2030 and 8 723 GW by 2050, under the 1.5°C Scenario of IRENA (2023b) and assuming an average capacity of 11 kW.

Modelling by the JRC (POTEnCIA) shows the capacity of individual heat pumps in the EU residential sector reaching more than 600 GW by 2050 in a scenario targeting climate neutrality (Figure 8). The capacity of centralised heat pumps for DHC would level off around 22 GW by that year.

Figure 8. Stock and capacity of individual heat pumps in the residential sector (left) and capacity of centralised heat pumps for district heating and cooling (right), 2025-2050



Source: JRC POTEnCIA.

Note: 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. Results shown here refer to its CETO Climate Neutrality Scenario, which reduces EU GHG emissions in 2030 in line with the targets of Fit for 55 and reaches climate neutrality in 2050.

Toleikyte et al. (2023) find that replacing 30 million fossil boilers with heat pumps under REPowerEU would reduce total final consumption of gas and oil by 36% for those buildings by 2030. The analysis takes into account the power generation mix in each country.

In their most recent (2019) National Energy and Climate Plans (NECPs),[22] all Member States expect to see an increase in final energy consumption (FEC) by heat pumps over the period 2020–2030. The highest increase can be seen in Spain (1 046%), followed by Hungary (467%), Belgium (234%) and Poland (195%). The highest FEC in 2030 is in Italy (5.7 Mtoe), followed by France (4.5 Mtoe) (Toleikyte and Carlsson, 2021).[23] These projections are likely to be even higher in the next round of NECPs.

Based on investment plans, the installed capacity of large heat pumps in DHC networks will increase by at least 80% by 2030 (EH&P, 2022). The share of large heat pumps in DHC in Europe could rise to between 25% (Paardekooper et al. in Jesper et al., 2021) and 40% (Ember, 2022) by 2050. Finally, the total potential of the industrial heat pump market in Europe is 730 TWh for applications up to 200°C (de Boer et al., 2020).

2.4 Technology costs

2.4.1 Up-front cost

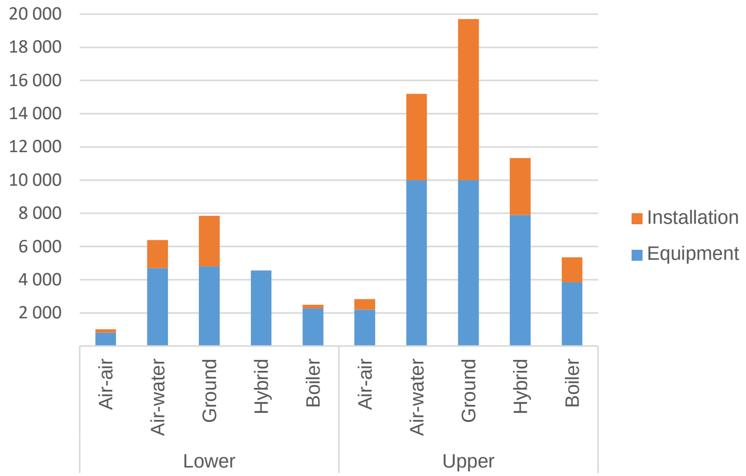
There is a lack of complete and timely data on costs of heat pumps, with and without subsidies, and taking installation into account. Work undertaken in the context of ecodesign indicates that the average manufacturer selling price for heat pumps in Europe in 2016 was EUR 3 600 per unit (VHK and BRG, 2019). Prices have risen since then and vary considerably by type, manufacturer and Member State. Trinomics (2023) uses an average of EUR 10 000 for the purchase and installation of an air-water heat pump, compared to around EUR 2 500 for a gas boiler.

Ground-source heat pumps tend to be more expensive in terms of CAPEX than air-water heat pumps (EUR 17 000 according to Trinomics), due to the need for underground piping, with air-air heat pumps more affordable on that metric (EUR 3 500). On the other hand, ground-source heat pumps tend to be more efficient in operation.

In the Netherlands, hybrid heat pump systems cost between EUR 5 500 and EUR 8 000 to purchase and install.[24] Installing underfloor heating or insulation at the same time takes the cost to around EUR 25 000.[25] Figure 9 summarises the available data.

[22] https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en.
[23] Data for Germany, Latvia and Lithuania not included.
[24] www.feenstra.com/zorgelooswonen/de-10-meest-gestelde-vragen-over-de-warmtepomp/?utm_source=nieuwsbrief&utm_medium=email&utm_campaign=nbweek0922_V1_B2C&utm_content=awareness.

Figure 9. Typical up-front costs for individual heating systems in the EU (euros)



Source: JRC, Toleikyte et al. (2023) and Trinomics (2023).

Notes: Air-air = 5-6.5 kW; Air-water = 7-9 kW; Ground = ground-water 7-9 kW; Hybrid = 5 kW; Boiler = gas boiler 14 kW. No data for Hybrid Installation Lower.

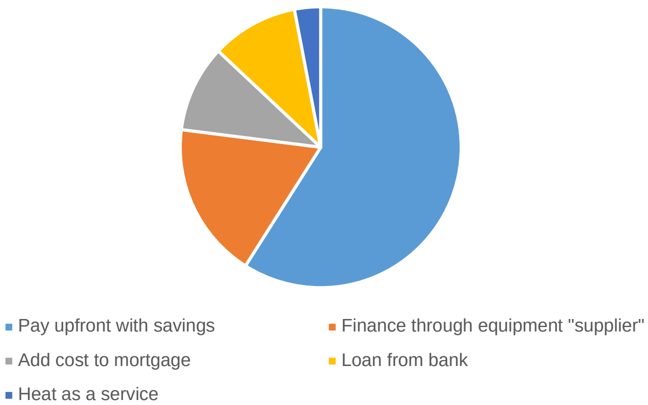
It should be noted that, unlike boilers, the heat pump systems often provide cooling or ventilation in addition to heating. In some countries it might be appropriate to compare the heat pump cost to the combined cost of a boiler and air conditioning.

It is also important to take into account the available subsidies. Subsidies for the purchase of a heat pump in the EU range from effectively none (Bulgaria, Estonia, Greece, Romania) to as much as EUR 16 750 (Germany, for a ground-source heat pump) or 90% (Italy, in the form of a tax break).

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.

Profit margins on heat pumps are expected to decline over time as the market expands, just as profit margins on boilers steadily declined in the past. In response, and in order to overcome the up-front cost barrier, new business models and finance will play a greater role as heat pump deployment continues (see also Box 5 below). There are already many potential customers for such solutions (Figure 10). All-inclusive packages covering installation, maintenance and repair seem to be particularly attractive, possibly due to perceptions of heat pumps being prone to failure (Dean, 2023).

Figure 10. Homeowners' preferences for funding a new heat pump installation



Source: LCP Delta, 2023.

Notes: Results from European householders "considering buying a heat pump as their next heating appliance".

[25] https://group.vattenfall.com/press-and-media/newsroom/2021/vattenfalls-new-heat-pump-provides-homeowners-an-alternative-to-gas.

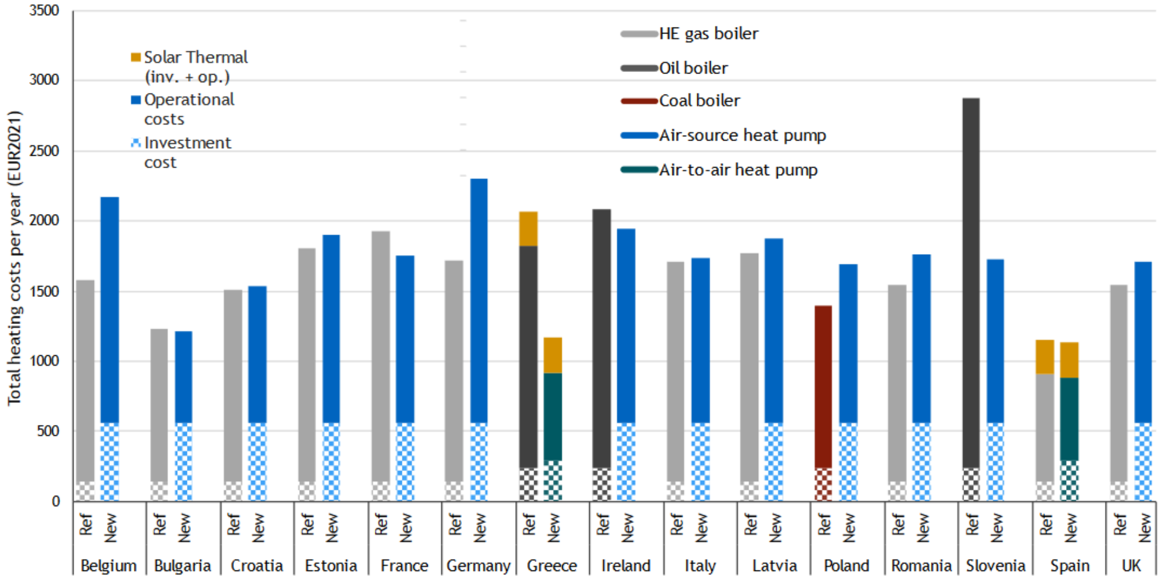
In countries with high shares of air conditioners, a final approach to reducing up-front cost that might hold promise is retrofitting. One study in Romania demonstrated that a relatively efficient air-water heat pump can be made at minimal cost by adding inverter technology to an existing air conditioner (Boțu et al., 2023).

2.4.2 Lifetime cost

Although the up-front investment is an important hurdle, the lifetime cost of a heating technology is dominated by its operation. The operating cost of a heat pump depends on electricity prices, the energy performance of the building, the size of the area to be heated, and the efficiency of the heat pump unit itself (Miara, 2021). Note that often a higher up-front cost is in part a result of greater efficiency, and thus reduces operating cost.

Looking at 15 European countries, Trinomics (2023) estimates that without additional policy measures an average subsidy of EUR 4 700 is required to reach a payback time of seven years. Nevertheless, heat pumps are already a cost-efficient alternative compared to fossil heating in many cases: in six of the countries, heat pumps already provide the lower lifetime cost without subsidies for a standardised reference household (Figure 11). In two countries (Slovenia and Greece), the payback time without subsidies is already less than seven years.

Figure 11. Total cost of ownership of fossil and low-carbon heating in selected countries, 2021



Source: Miara, 2021.

Notes: Ref = Fossil. New = Low-carbon. Heating costs are without any subsidies. 2021 energy prices are forecast for the lifespan of the heating system.

The relatively high gas prices of 2023 made heat pumps more attractive, partly explaining the boom in demand (Toleikyte et al., 2023). Nevertheless, the tax treatment of electricity relative to gas is still a key policy area affecting heat pump economics. This is currently being re-examined at both national and EU levels.

In 2021, a revision of the Energy Taxation Directive was proposed that would help level the playing field between electricity and gas. There is also a proposal in the Electricity Market Design for dual electricity tariffs for heat pump users. And since April 2022, Member States have the right to apply reduced Value Added Tax (VAT) rates to energy efficient, low emission heating systems, including heat pumps. So far however, only France has applied a lower VAT rate, and only for air-water heat pumps (EHPA, 2023c). At national level, in Finland for example electricity tax reform aims to reduce the electricity tax for heat pumps from 22.53 EUR/MWh to 7.03 EUR/MWh (Tilia et al., 2021).

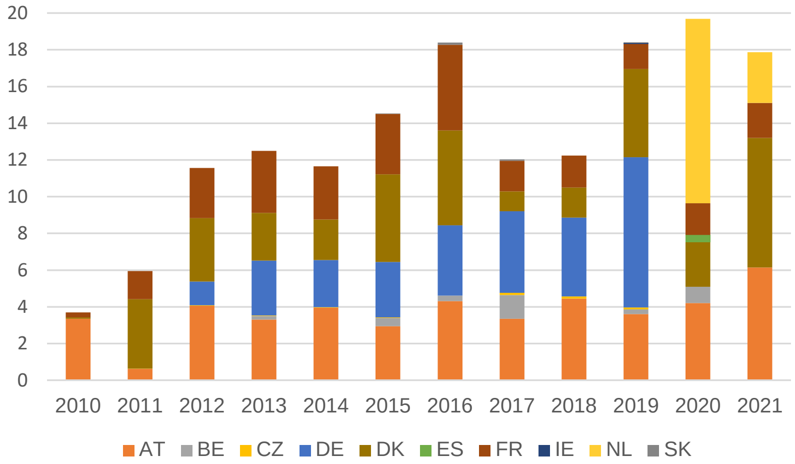
Electricity prices and taxes are also an important cost element for DHC. IRENA (2023a) describes the example of Sweden, where networks were developed with large heat pumps in the 1980s when there was surplus electricity, before the share of heat from heat pumps declined in favour of cogeneration due to higher electricity prices and taxes after 2000.

The cost of all heating and hot water systems has been increasing, in a context of inflation and supply bottlenecks. In Germany, work on such systems cost 19% more in January 2023 than in January 2022 (Destatis, 2023). Nevertheless, the cost of heat pumps has been falling over time and is expected to resume doing so as the market grows and technologies develop.

2.5 Public funding for research, development and innovation

Public RD&I investment into heat pumps in the EU started to be reported to the IEA in 2010, with eight Member States submitting data since then (Figure 12). The data are incomplete but the overall trend is towards a gradual increase in funding.

Figure 12. Public investment into heat pump research, development and innovation in the EU, 2010-2021 (EUR millions)



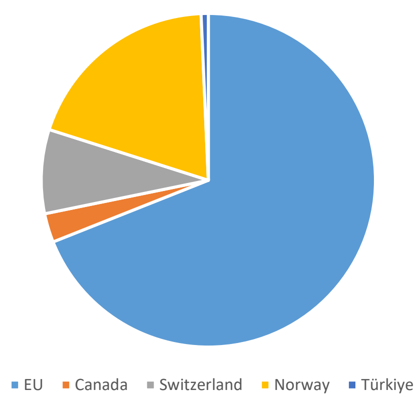
Source: JRC based on IEA (2023) and BMWi (2019).

Notes: Data are for code 144 (heat pumps and chillers, excluding simple cycle air-conditioning only units or room air conditioner units). IEA data are limited to its member countries. Data for Germany from 2012 to 2018 is for "Heat pumps, refrigerants" reported under "Energy efficiency in industry, commerce, trade and services".

Germany reported data for the first time in 2019 (EUR 8.2 million), so the time series above has been completed based on statistics at national level for large heat pumps only. In addition, Germany's Federal Ministry of Economic Affairs and Energy (BMWi) is funding a project (REALLABOR GWP) on heat pumps in DHC networks with EUR 21 million that started in 2021 (IEA HPT, 2021). Yet Germany has not reported any data for 2020 or 2021. Meanwhile, the Netherlands' reporting starts in 2020, with EUR 10.1 million.

Although public RD&I funding for heat pumps is small compared to some other clean energy technologies (for example, Germany's total outlays at federal level in 2018 were more than EUR 1 billion), the EU spends a significant amount on public research into heat pumps relative to several major countries worldwide (Figure 13). Still, it is notable that data are not available for other major world regions and that European Free Trade Association members Norway (reporting for the first time in 2020) and Switzerland make significant investments in heat pump RD&I also.

Figure 13. Public investment into heat pump research, development and innovation, 2020



Source: JRC based on IEA, 2023.

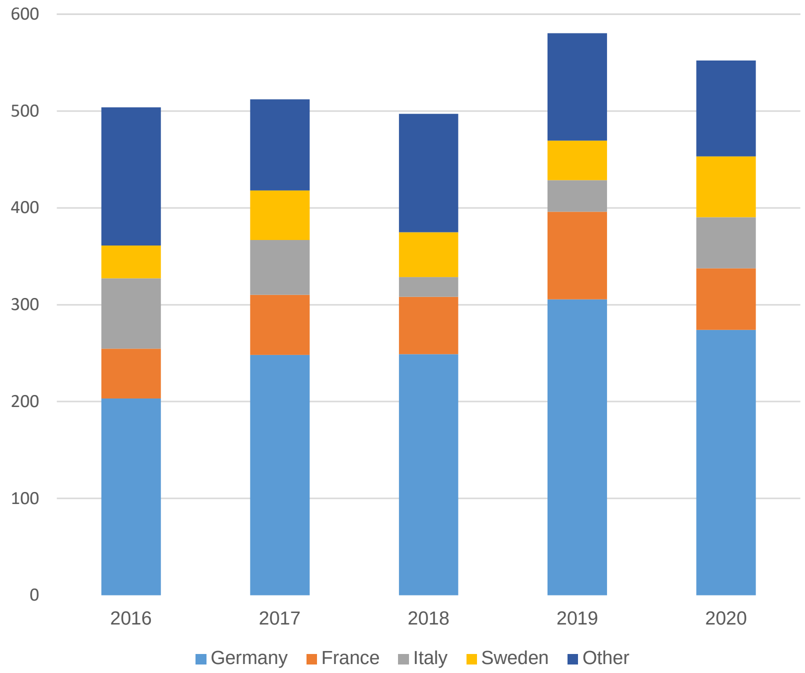
Note: Total = EUR 25.9 million.

As well as national research programmes, funding obtained through EU programmes is included in the data above. EU support for RD&I into heat pumps is provided mainly through Horizon 2020 and Horizon Europe, with 59 ongoing and completed projects worth around EUR 350 million (CINEA, 2023). Those projects span design, manufacturing, installation, operation and other areas such as disposal, business models or skills. Support is also provided through the Innovation Fund (two small-scale projects) and the LIFE programme (the EU funding instrument for the environment and climate action). Much of this funding is also available for research into large heat pumps for industry and DHC.

2.6 Private funding for research, development and innovation

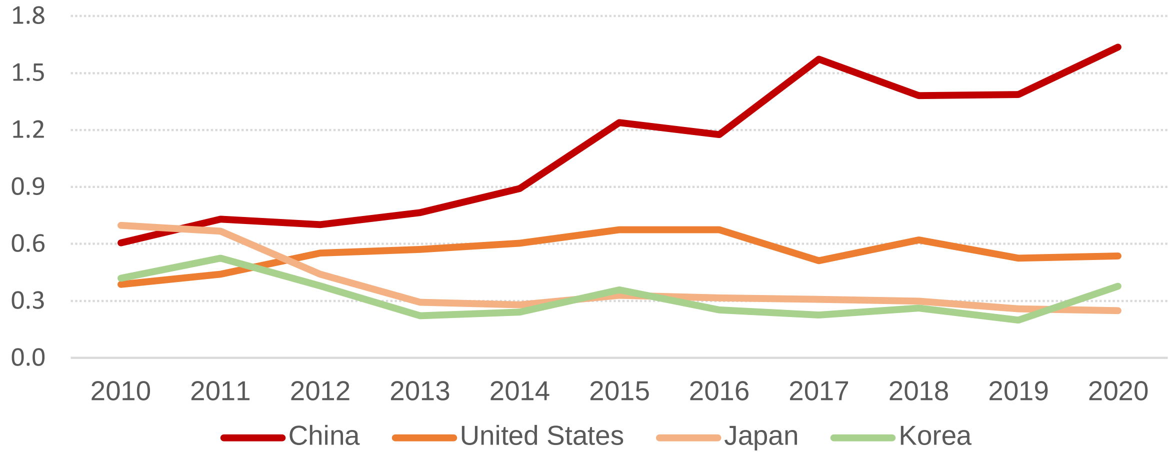
Private RD&I figures are estimated using patenting as a proxy. Data are therefore subject to a lag and potential revision. Bearing that in mind, 2020 saw a slight drop in EU investment compared with 2019, with increases in Italy and Sweden outweighed by decreases in Germany, France and other Member States (Figure 14). Internationally, private RD&I increased over the period 2010-2020, with a decline in Japan outweighed by an increase in China (Figure 15).

Figure 14. Private investment in heat pump research, development and innovation in the EU, 2016-2020 (EUR millions)



Source: JRC based on patent data.

Figure 15. Private investment in heat pump research, development and innovation by country, 2010-2020 (EUR billions)

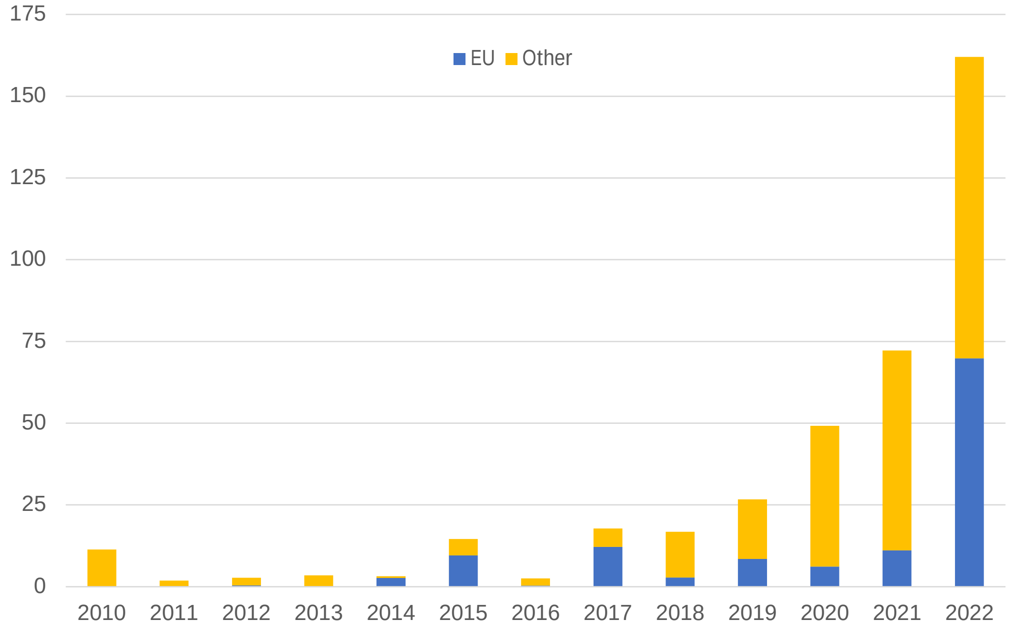


Source: JRC based on patent data.

Investment in heat pump start-ups in the EU jumped from EUR 11 million in 2021 to almost EUR 70 million in 2022.[26] This was a 630% increase, compared to a 151% increase elsewhere (Figure 16). There was a marked shift in 2022 towards later-stage investment (Figure 17).[27]

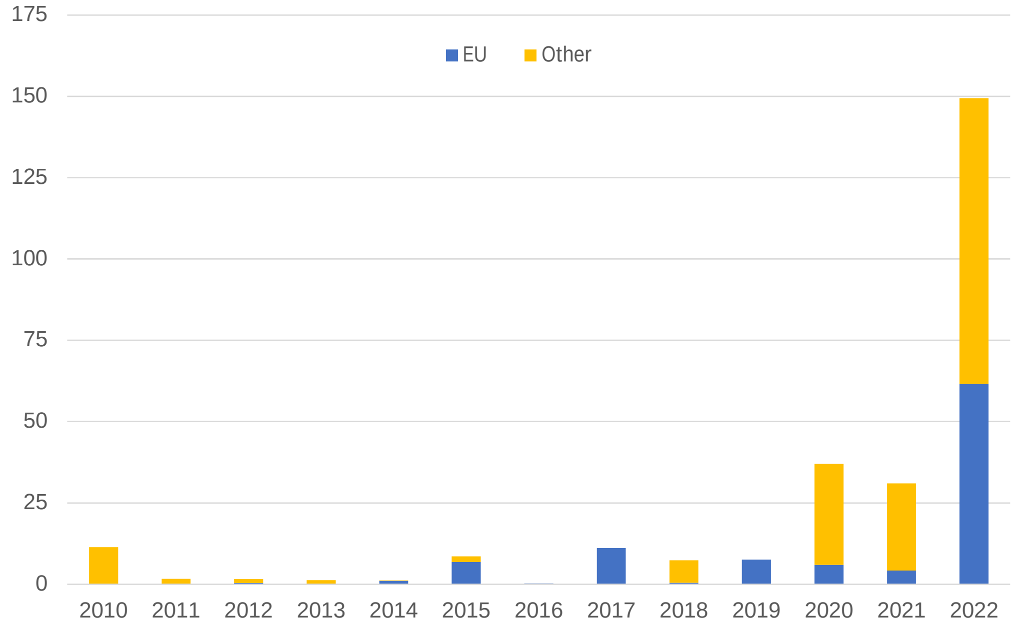
At both early and later stages, the United States is ahead of individual Member States. The next leading countries are the Netherlands for the early stage (overtaking Norway in 2022) and Ireland for the later stage.

Figure 16. Investment in heat pump start-ups, 2010-2021 (EUR millions)



Source: JRC based on Pitchbook.

Figure 17. Later-stage investments, 2010-2021 (EUR millions)



Source: JRC based on Pitchbook.

[26] By start-ups, we mean pre-venture companies and venture capital companies. Pre-venture companies have received angel or seed funding, or are less than two years old and have not received funding. Venture capital companies are companies that have, at some point, been part of the portfolio of a venture capital firm.

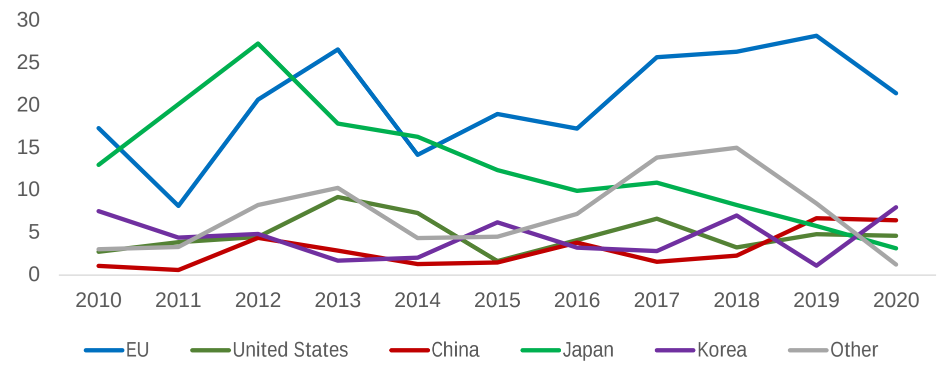
[27] Types of early-stage private investment include grants, pre/accelerator/incubator, angel, seed and early-stage VC investments; types of later-stage private investment include later-stage VC (including undisclosed series), small mergers and acquisitions (non-control) and growth private equity.

2.7 Patenting

Patents that are relevant to heat pumps may be reported under a variety of codes. In particular, there is a high degree of overlap with refrigeration, air conditioning and climate control in cars. The scope in this section is the Cooperative Patent Classification (CPC) code Y02B (climate change mitigation technologies related to buildings, e.g. housing, house appliances or related end-user applications).[28]

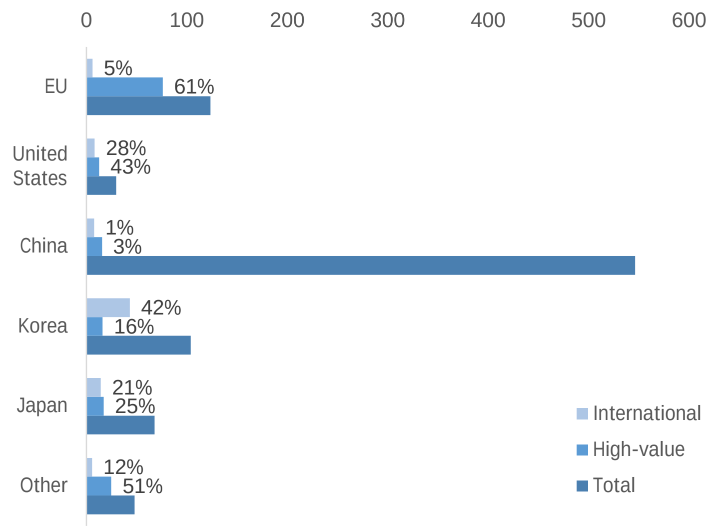
The EU is a world leader in heat pump technology (Figure 18). Only 3% of Chinese inventions are high-value patents,[29] compared to more than 60% of EU inventions (Figure 19).

Figure 18. Number of high-value inventions for mainly heating heat pumps by region, 2010-2020



Source: JRC based on EPO Patstat.

Figure 19. Number of inventions and share of high-value and international activity, 2018-2020



Source: JRC based on EPO Patstat.

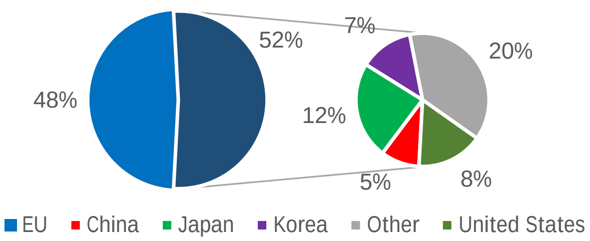
Notes: CPC codes for all charts in this section are Y02B 10/40 (geothermal heat-pumps), 30/12 (hot water central heating systems using heat pumps), 30/13 (hot air central heating systems using heat pumps), and 30/52 (heat recovery pumps).

The EU share of all high-value patents was 47% during the period 2018-2020 (Figure 20). Germany had a clear lead, with France, Sweden, Italy and the Netherlands also among the top ten countries worldwide (Figure 21).

[28] Patent families (inventions) include all documents relevant to a distinct invention (e.g. applications to multiple authorities). Statistics are produced based on applicants, considering applications to all offices and routes. When more than one applicant or technology code is associated with an application, fractional counting is used to proportion effort between applicants or technological areas, thus preventing double-counting.

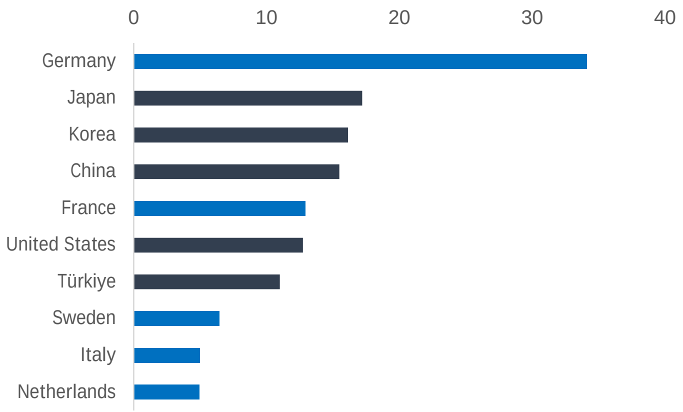
[29] An invention is considered high value when it contains patent applications to more than one office. Patent applications protected in a country different to the residence of the applicant are considered as international. High-value considers EU countries separately, while for international inventions European countries are considered collectively. The CPC classification is not used with the same degree of consistency across IPOs in Asia. The figures for the total number of inventions for Asian countries should be used with caution. This does not affect statistics for high-value and international inventions.

Figure 20. Share of high-value inventions for mainly-heating heat pumps by region, 2018-2020



Source: JRC based on EPO Patstat.

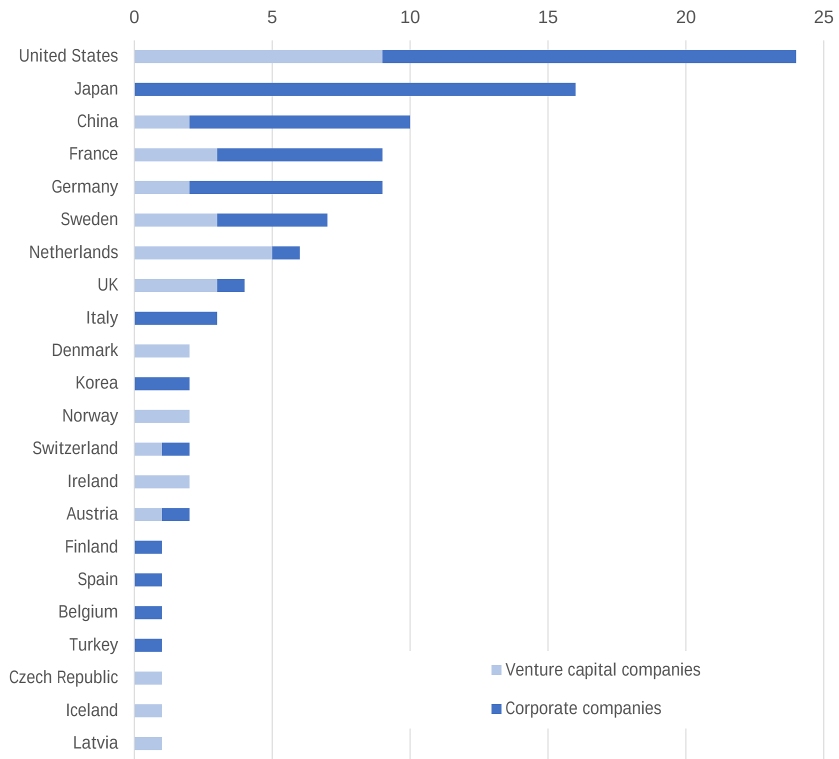
Figure 21. Top ten countries for high-value inventions, 2018-2020



Source: JRC based on EPO Patstat.

The EU as a whole is host to 41% of all innovating companies. The United States has a strong base of venture-capital funded companies, while all innovators in Japan are larger corporations (Figure 22). The Netherlands has more start-ups than any other Member State.

Figure 22. Number of innovating venture capital companies and corporates by country, 2017-2022



Source: JRC based on various sources.

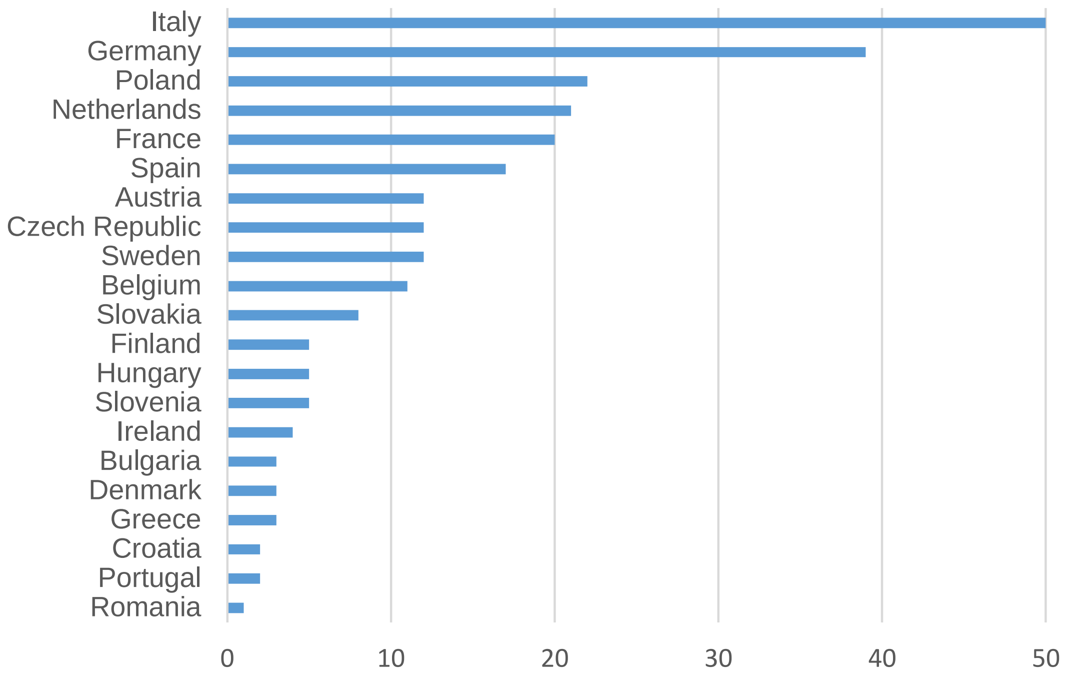
3 Value Chain Analysis

3.1 Role of EU companies

There are very few dedicated heat pump manufacturers and they are among the smaller players in the market. Most heat pumps in the EU are sold by manufacturers of gas boilers, air conditioners or other products. Similarly, for most manufacturers of components, heat pumps form a small part of their customer base. Therefore when we refer to the EU heat pumps sector, we refer to the specific product segments concerned, rather than a distinct group of companies.

There are more than 255 facilities in the EU that manufacture (i.e. assemble) heat pumps, across 21 Member States (Figure 23). Italy and Germany lead at country level, although eastern Europe competes strongly as a region.

Figure 23. Heat pump manufacturer locations in the EU by country



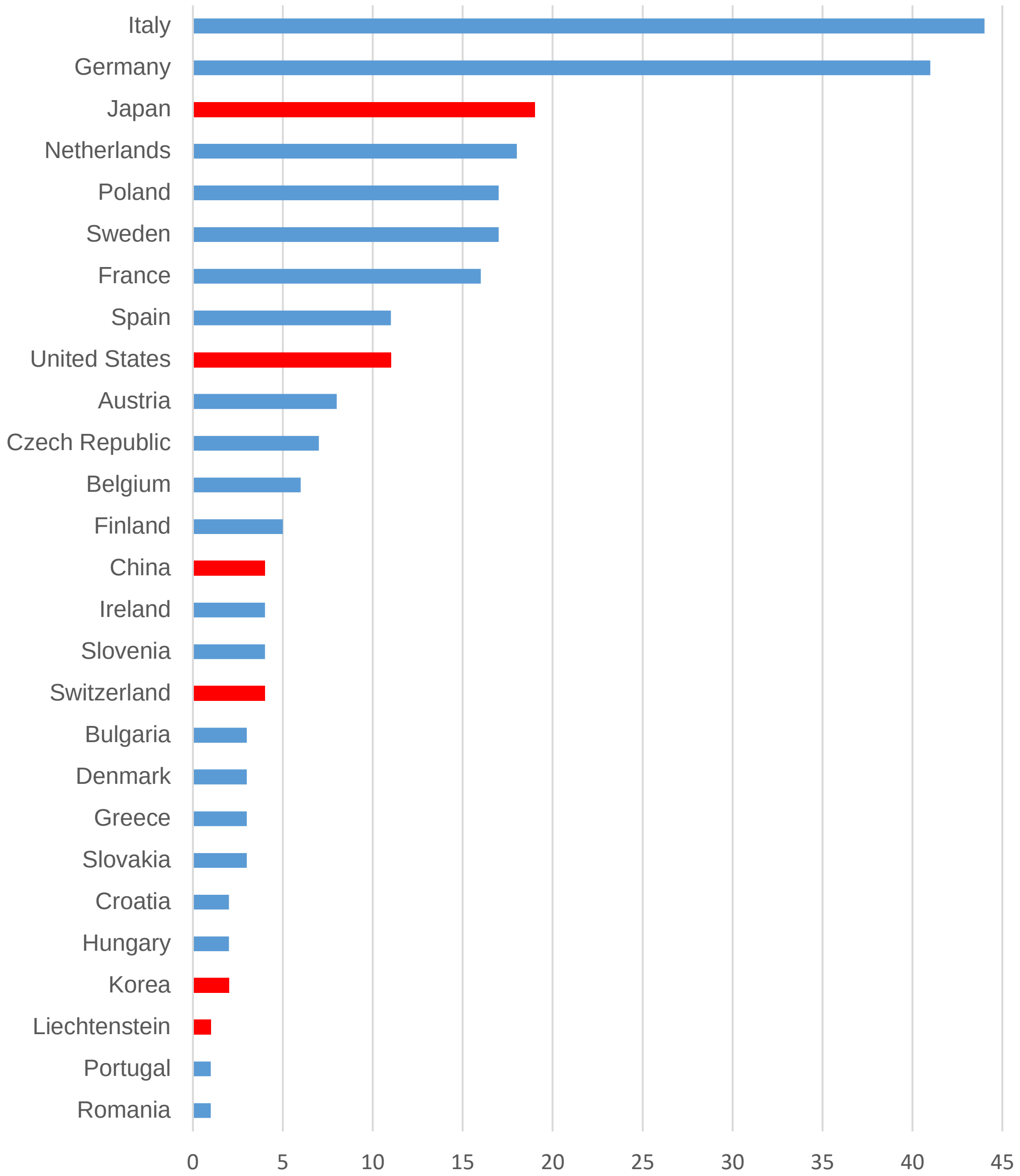
Source: JRC based on various sources.

Note: Includes companies present in multiple countries but does not count multiple manufacturing sites in the same country. Excludes component manufacturers.

There is a mix of EU ownership or headquarters location (e.g. Bosch, the privately owned manufacturer of car parts, appliances and other equipment including gas boilers and hydrogen technology) and local subsidiaries of extra-EU brands (e.g. Daikin, the air conditioner manufacturer). Companies use a variety of ownership structures and local brand strategies, making analysis complex, but Italy and Germany again seem to lead in terms of parent country, with significant investments by non-Member States such as Japan as well (Figure 24).

CE Delft (2023) estimates that 75% of the heat pump brands being sold in Europe have manufacturing facilities here. There are also heat pump companies based in Norway (e.g. Winns Energy), Switzerland (e.g. CTA), the UK (e.g. Kensa Heat Pumps) and Türkiye (e.g. Arçelik). United States companies in the heat pump value chain include Carrier (with subsidiaries in France, Italy and Poland, as well as the recent acquisition of Viessmann for around EUR 12 billion), Johnson Controls (with subsidiaries in Denmark and France), Lennox, Rheem and Trane (Ingersoll Rand, with a subsidiary in Belgium). Chinese manufacturers of air-source heat pumps include Midea, Gree and Haier. Other major players are Daikin (Japan, with subsidiaries in Belgium, Czech Republic and Poland), LG (Korea), Mitsubishi Electric (Japan with subsidiaries in Germany, Italy, the Netherlands and the UK) and Panasonic (Japan, with subsidiaries in Czech Republic, Germany and Spain).

Figure 24. Heat pump manufacturer locations in the EU by country of parent company



Source: JRC based on various sources.

Notes: Blue = Member State. Red = Others.

As a market of 27 Member States and other countries in the common market, spanning a continent with a diverse building stock and climate, the sector contains a large number of companies relative to its size. Nevertheless, some consolidation has recently taken place in the sector:

– 2023, Carrier acquired Viessmann; Ariston (Italy) acquired the Wolf brand of heat pumps (Germany); Qvantum (Sweden) acquired a refrigerator manufacturing facility in Hungary from Electrolux for EUR 38 million that it plans to convert to heat pump manufacturing with a capacity of one million units; in the DHC and industrial market, Johnson Controls acquired Hybrid Energy (Norway).

– 2021, Groupe Atlantic (France) acquired Hautec (Germany).

– 2020, Nibe (Sweden) acquired Waterkotte (Germany).

– 2019, Hisense (Chinese joint venture with Johnson Controls Hitachi) acquired Gorenje (Slovenia).

– 2018, Stiebel Eltron took over Thermia (Sweden), a heat pump brand from Danfoss (Denmark and Italy); Nibe acquired the DHC and commercial hot water systems of Alfa Laval (Sweden).

- 2016, Midea acquired an 80% holding in the Clivet group, and relocated manufacturing of domestic hot water heat pumps from Asia to Italy in 2017.
- 2015, Carrier acquired 70% of Riello (Italy).

In addition to mergers and acquisitions, there are many partnerships and distribution agreements in place:

- 2022, Trane announced that it would reduce the carbon impact of its heat pumps and air conditioners for homes and commercial buildings by buying low-carbon steel from Nucor and United States Steel (both United States).
- 2019, Viessmann signed a partnership agreement with KE KELIT (Austria) in which KE KELIT will distribute Viessman's condensing gas and diesel boilers, controllers, and hot water heat pumps; Panasonic collaborates with Systemair (Netherlands) on development.
- 2018, Ingersoll Rand signed a joint venture with Mitsubishi Electric for distribution of heat pumps and air conditioners.
- 2017, Stiebel Eltron partnered with Denso (Japan with a subsidiary in the Netherlands and 5% owned by Bosch) to develop a new air-air CO_2 heat pump.
- Groupe Atlantic has a co-branding arrangement with Fujitsu (Japan) in France.
- Manufacturers often partner with specific digitalisation providers, instead of (or in complement to) in-house solutions.

Component manufacturers are fewer in number (at least 26) and mostly large companies serving several industry sectors. For example, 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 said by industry associations to be imported from China and Japan. European players include Danfoss, Bitzer (Germany), Tecumseh (France) and Emerson Copeland (Germany and Romania). Some of the larger Asian electronics manufacturers, such as Hitachi and Daikin in Japan, manufacture their own compressors. Mitsubishi Electric manufactures compressors in Thailand.

Fans are mainly manufactured by Ziehl-Abegg and ebm-papst (Germany); fans are used in many products, including in clean energy technologies such as electric vehicle charging and battery storage. The pumps market is dominated by Wilo (Germany) and Grundfos (Denmark).

Manufacturing of components such as heat exchangers, housing and controllers is less specialised (they are also used in other products) and distributed among a wider range of companies worldwide. However, European companies Danfoss, CAREL (Italy), Alfa Laval and SWEP are leading in many components.

Suppliers of materials or components (including controls) also include ABB, ArcelorMittal, Aviva Metals, Fuji Electric Co., General Electric, Hitachi, MetalTek, Mitsubishi, Panasonic, Schneider Electric and Siemens. Manufacturers of elastomers include BASF (Germany), Dow (United States) and JSR (Japan). Semiconductors have very complex value chains of their own.

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 and Daikin; SRF (India); and Koura (Mexico). EU suppliers are Arkema (France) and the Linde Group (Germany).

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 (see also Box 5). thermondo offers rental rather than sale of the heat pump; the start-up Aira (Sweden and Italy) offers heat pumps on a monthly subscription. In 2022, rentals already accounted for 4% of total heat pump installations in Germany (LCP Delta, 2023).

Box 5. The heat pump business model

The dominant business model in the heating sector today is to manufacture a boiler and sell it to a customer via a wholesaler or installer. Value is created by manufacturing, installing and maintaining the product as well as by providing the energy to operate it.

For larger heat pumps, other business models are already in place: the end user pays for the delivery of heating and cooling in a service model (see for example the Norwegian company Aneo in the industry sector). Digitalisation can now make this approach feasible for aggregated heat pumps or even individual units (see also Box 2).

With a redefined value proposition, the offering is no longer a physical product but a package consisting of hardware, software and support for planning, financing, insurance, maintenance, etc. Heating and cooling becomes a service that the user enjoys and pays for, while the service provider takes ownership and is also responsible for system design and operations. Optimising design, monitoring operations and providing timely maintenance leads to reduced operating cost and thus optimised profit.

A service provider would integrate all the necessary steps from system design to integration, add the necessary sensors and control systems and be the direct link to the end user, in return reaping all the benefits from the system. In this way, the workings of the heating and cooling system would no longer matter to the user, as long as the required function is provided. Such an approach could have far reaching effects on the brand value of the current market leaders and on their ability to set high prices for their products.

Any of these new value propositions could be offered by existing actors but it is expected that new players will take an active role in their development, in particular those with access to sensors and digital technologies (e.g. the Google Nest thermostat). Similarly, large utilities could commercialise their knowledge of large-scale roll-out of products and services. Having access to user data already could be a headstart for those players.

Source: Based in part on Nowak, 2018.

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 (11 production sites in Europe and three in Asia), Mayekawa (Japan with subsidiary in Belgium), Metro Therm, Ochsner, Sabroe (Johnson Controls), Siemens Energy (a spin-off of Siemens with activities across fossil and renewable sectors), Turboden (Mitsubishi Heavy Industries), Vattenfall and Wien Energy.[30] Again, in almost all cases heat pumps is only part of these companies' activities.

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. Switzerland, Germany and Italy are leading in terms of number of companies by country. Engie, Sweco and others provide Energy Performance Contracting.

Testing or research centres include 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) and KTI Stockholm (Sweden). The main manufacturers also have their own research centres. In industrial heat pumps, prominent research organisations in the EU include TNO and University of Lyon (France).

Heat pumps are represented by a number of associations both at national and EU levels. Some of the main associations at EU level are EHPA, Euroheat & Power (representing the DHC sector), EHI, EGEC, ATMOsphere (representing natural refrigerants) and the European Partnership for Energy and the Environment (EPEE). 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 organisations active in the segment too.

[30] For examples of DHC networks using large heat pumps, see (EHPA, 2019) or www.pv-magazine.com/2022/03/29/large-scale-high-temperature-heat-pump-for-district-heating/.

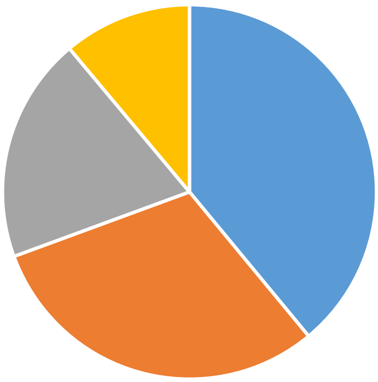
3.2 Employment and skills

3.2.1 Employment

In Europe, China and the United States alone, heat pumps employed 350 378 people in 2022 (IRENA, 2023c). In Europe alone, employment was 161 632 in 2022, increasing roughly in line with deployment (EHPA, 2023a). The projected growth in installations to 2030 would employ many more, notwithstanding economies of scale and productivity improvements.

The heat pumps sector employs people in RD&I, manufacturing, installing (including drilling), and maintenance (including periodic checks) (Figure 25). It is possible that component manufacturing employs even more people than final assembly, depending on the companies and shares of activity that are counted. JRC (based on EHPA and Orbis) estimates that heat pump assemblers employed 52 000 people in 2021, and component manufacturers employed 67 000. Women's participation in the workforce is low (16%), and even lower than the batteries, hydrogen, wind or solar sectors (EC, 2023).

Figure 25. Employment in the heat pump sector by stage of the value chain, 2022



Source: Based on EHPA, 2023a.

Note: Total = 161 632.

All heat pumps, whether imported or domestically produced, need to be installed on site. It takes more than twice as long to install a heat pump as it does to install a boiler, especially when that heat pump is replacing an existing boiler (EHI, 2021a). Ground- or water-source heat pumps take far longer to install than air-source heat pumps because they require drilling or digging.

There are about 1.5 million installers of all kinds of heating appliances, most of them small companies (EHI, 2022). Industry associations estimate between 500 000 and 750 000 additional skilled workers are needed by 2030, and 50% of existing installers will need reskilling. Instead, the number of installers is stagnant in several European countries.

The European heating sector as a whole accounts for about 1.8 million direct and indirect jobs (EHI, 2021a).[31] That is around 0.5% of the EU labour market.

There are shortages of planners, architects, engineers and qualified heating and cooling installers in several Member States. This barrier is common across heating and cooling technologies but more acute in heat pumps. Bottlenecks at the installation stage are already being experienced in several Member States. There is also a general shortage of factory workers in the EU, although concomitant phase-out of gas boiler manufacturing might help. Less restrictive migration policies, both generally and for highly skilled professionals, would also alleviate the shortages.

3.2.2 Skills

This is a deficit in skills as well as workers. There is a lack of heat pump-specific skills in the curricula for the relevant trades (e.g. plumber, electrician, heating technician), and issues with skills recognition across Member

[31] EHI data covers Austria, Belgium, Denmark, France, Germany, Italy, the Netherlands, Spain, Sweden, Switzerland and the UK. Data for Germany and Italy include hybrid systems.

States. There are particular needs for skills in installing integrated systems, in digitalisation, in refrigerants and in ground-source heat pumps (including drilling).

The Renewable Energy Directive (RED) requires installers to have a specific certification in order to install heat pumps. Also, the F-Gas Regulation requires anyone who installs, services, repairs or decommissions heat pumps with HFCs to do leak checks or to reclaim HFCs to be certified. Therefore, installers of heat pumps and other experts need to be trained specifically in relation to refrigerants and dimensioning of the system, in order to handle heat pumps safely, ensure their optimal performance and prevent emissions. The Commission proposal for a new F-Gas Regulation also includes certification based on obligatory training in climate-friendly refrigerants, but the obligation will not apply retrospectively to existing installers.

Action is required at sectoral, national and EU levels. Training courses are currently provided by heat pump manufacturers themselves (Viessmann, for example, has launched a training scheme on flammable refrigerants), by trade associations and by research centres.[32] Upskilling of existing installers of boilers to work with heat pumps can take from a few days to three or four weeks.

At EU level, training for heat pump installers is supported by the HP4ALL project under Horizon 2020.[33] More broadly construction and renovation skills including for heat pumps are supported by BUILD UP Skills, with its ongoing country analyses and 2030 roadmaps,[34] by Erasmus+ and by the LIFE programme. Further support at EU level could come from the Technical Support Instrument or the Pact for Skills.

If an industrial heat pump market can be established in Europe with a market rollout of 37 TWh per year, 14 500 new jobs would be created (de Boer et al., 2020). Technology export would increase that number further. However, the integration of heat pumps in industry requires knowledge of both the capabilities of heat pumps as well as the underlying process in which they can be applied. Currently, there are few installers or decision makers who combine this knowledge.

3.2.3 Labour productivity

Heat pump manufacturers often also produce other heating systems such as gas boilers. Compared to boilers, more material is necessary and the assembly time is longer. Installation and maintenance also take longer. There is therefore considerable potential for job creation.

Labour productivity (turnover divided by employment) in heat pump manufacturing was EUR 129 864 in 2022, down slightly from EUR 153 846 in 2021. In the future 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. During the period 2015-2021, labour productivity in assembly in the EU already increased by 32%, as turnover grew faster than employment (JRC based on EHPA and Orbis). Based on a selection of sites, an average of six jobs are created for each thousand units of heat pump manufacturing capacity that is added (Table 3).

Table 3. 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	1000	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

Source: JRC analysis based on company websites, EHPA and EC.

The job creation potential is much greater in installation and maintenance than in manufacturing. Comparing data on sales, stock and employment, we can calculate that a manufacturing worker assembles of the order

[32] See for example www.waermepumpe.de/fuer-handwerker/training, https://ecoforest.com/academy/en, www.viessmann.family/en/career/academy, www.daikin.nl/nl_nl/daikin-academy.html, www.cetiat.fr/en, www.eurac.edu/en/institutes-centers/institute-for-renewable-energy/pages/heat-pumps-lab, https://www.qualit-enr.org/qualifications/qualipac/.

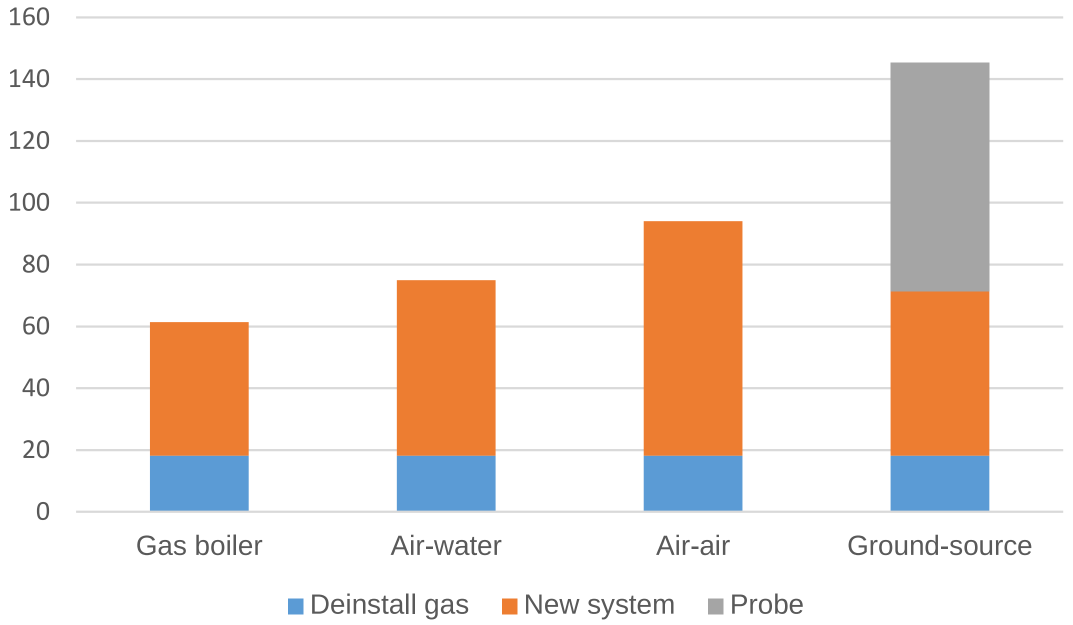
[33] https://hp4all.eu/.

[34] See https://build-up.ec.europa.eu/en/bup-skills.

of 300 heat pumps per year; an installer deploys around 61 heat pumps; and a technician maintains or services a stock of around 1 100.

Based on survey data from Germany (Figure 26), the installation time also likely includes a significant planning and transport element. Factors influencing installation time include qualification of workers, transport distances, accessibility, co-ordination with other construction services, weather, the existing heating system, and room layout (Richarz et al., 2023).

Figure 26. Installation time by modernisation measure (person-hours)



Source: Based on Richarz et al., 2023.

Productivity at this stage of the value chain could be improved through standardisation, economies of scale, digitalisation or plug-and-play technology.[35] 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).

3.3 EU production

In unit terms, France, Germany, Sweden and Italy are likely the Member States that manufacture the greatest number of heat pumps (CE Delft, 2023). Germany and Sweden produce a greater share of more expensive ground-source heat pumps than France or Italy.

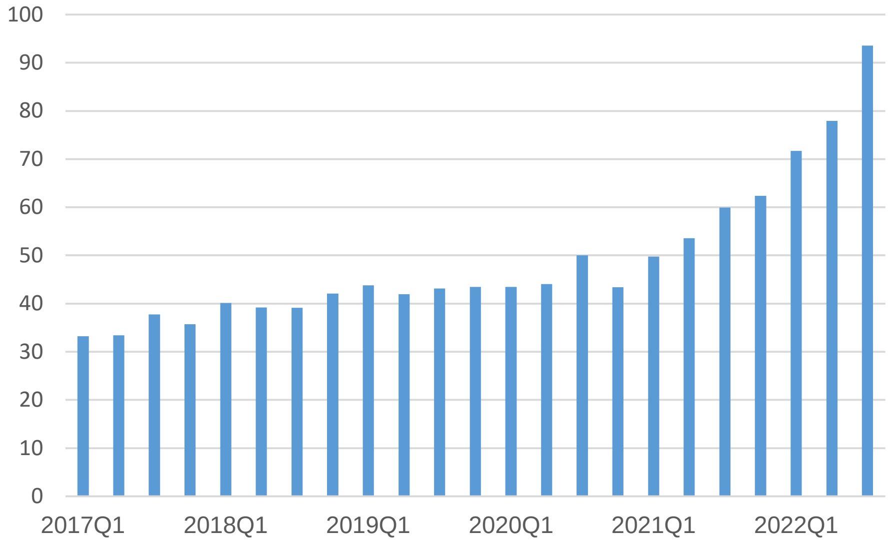
The value of EU production of heat pumps mainly used for heating was EUR 4.2 billion in 2022, a big jump from EUR 2.8 billion in 2021 (JRC based on PRODCOM code 28251380). The impact of the pandemic was felt in 2020, with production almost unchanged that year at EUR 2.3 billion. This is a narrower definition than that used for turnover.

Sweden was the top producer in value terms (EUR 931 million), notably hosting the manufacturer Nibe. Germany also remains a top producer, with an increase of 38% to EUR 884 million. Among smaller producers, production in Finland doubled in 2022 to EUR 30 million, having already increased eightfold in 2021.

These trends are in large part the result of stronger grant schemes and target announcements. Production of heat pumps in Germany was up 49% in the first three quarters of 2022 compared with the same period of 2021 (Destatis, 2023), to reach 243 200 units (Figure 27). France aims to increase manufacturing fourfold to 1.3 million heat pumps by 2030, including 300 000 for export (Le Monde, 2023).

[35] Gradient is a start-up in the United States offering a window air conditioner that can be installed by the user, see www.gradientcomfort.com. Another example is the Powrmatic Vision air conditioner, which also provides a heating function: www.linkedin.com/pulse/evolution-monobloc-air-conditioningheat-pump-unit-paul-greenough/. Extending these concepts to other heat pump types would be a considerable challenge, notably because of the electrical and plumbing work required.

Figure 27. Quarterly heat pump production in Germany (thousand units), 2017-2022



Source: Destatis, 2023.

Manufacturers are investing in the EU to satisfy increasing market demand. Ongoing investments as of 2023 total EUR 4.8 billion, with a further EUR 1.1 billion in components manufacturing. Based on a selection of these (Table 4), the cost of expanding manufacturing capacity is of the order of EUR 950 per unit.

Table 4. Ongoing investments in heat pump manufacturing capacity in the EU, 2023

Company	Country	EUR millions	Thousand additional units	EUR millions per thousand units
Saunier Duval	France	9.3	95	0.1
Vaillant	Slovakia	120	75	1.6
BDR Thermea	France	70	53	1.3
BDR Thermea	Italy	70	53	1.3
BDR Thermea	Netherlands	70	53	1.3
BDR Thermea	Spain	70	53	1.3
Daikin	Poland	300	220	1.4
Stiebel Eltron	Germany	600	240	2.5
Bosch	Portugal	12	150	0.1
Clivet (Midea)	Italy	60	100	0.6
Panasonic	Czech Republic	145	500	0.3
Hoval	Slovakia	60	30	2.0
Atlantic	France	120	170	0.7

Source: JRC analysis based on company websites, EHPA and EC.

Note: Calculation for BDR Thermea assumes an equal spread across manufacturing sites.

As a whole, the heat pump sector is on track to invest enough to meet projected production in 2030 and beyond. EHPA projects investments so far to bring European manufacturing capacity to 5 million units per year. Sales in Europe are expected to grow from 2.2 million in 2021 to 9.8 million in 2030. Total investment of EUR 9.2 billion over the period would therefore be needed, with imports also likely to play a role in practice.

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 construction of some new production sites. In some cases, investments in RD&I capacity are made at the same time. 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 poorer regions (EC in Deutsche Bank Research, 2023).

4 EU market position and global competitiveness

4.1 Market size

The world heat pump market is about EUR 56 billion today, and is projected to rise to about EUR 108 billion in 2030, according to various market research studies. It needs to grow to an annual average of USD 230 billion over the period 2023-2050 under the 1.5°C scenario of IRENA (2023b). Europe is the fastest growing region but Asia-Pacific is the largest, with a share of about 53%.

Focusing on heat pumps used for heating and hot water, manufacturers in Europe generated EUR 18 billion in 2021 (JRC based on EHPA and Orbis). Component manufacturers generated a further EUR 15 billion. Turnover grew by 8% per year on average between 2015 and 2021.[36] EHPA (2023a) reports manufacturing turnover of EUR 14.5 billion in 2022.

If an industrial heat pump market can be established in Europe with a market rollout of 37 TWh per year, i.e. 5% of the total potential, the total turnover for the entire value chain would be EUR 2.3 billion (de Boer et al., 2020). Technology export would increase that number further.

4.2 Global and EU market leaders

Europe is a recognised market leader in all types of heat pumps, and especially in hydronic heat pumps (especially ground-source) and large heat pumps (along with Japan). Its leadership is more evenly spread across the complete range of heat pump types than other markets, some of which are more specialised in air-air systems. The EU is a technology leader in use of natural refrigerants, in noise reduction and energy efficiency, and in sorption heat pumps. Continued technology leadership, for example as fostered by the Ecodesign Regulation, may represent an export opportunity, or a way to maintain future competitiveness with respect to potential extra-EU imports.

Most heat pumps installed in the EU are made in the EU, with the domestic market share estimated between 55-60% (CE Delft, 2023) and 73% (JRC) of value.[37] However, there is a growing share of assembled heat pumps being imported, particular from China (see next section).

Most components are purchased from other companies based in Europe or more often further afield, mainly Asia. Based on communication from EHI, EU-based manufacturers are leaders in the market for those components typical of combustion technologies and used in hybrid heat pumps and gas heat pumps, and for storage tanks, and expansion vessels for indoor units. In addition, indirect cylinders and buffer tanks are strategic components of every heat pump and are mainly produced in the EU.

The expansion valve stepper and the 4-way valve for the outdoor units of electric and hybrid heat pumps seem to come exclusively from China. For the other components, there is a mix of EU manufacturing and imports from outside the EU, with imports appearing to be higher for key components such as the compressor and the inverter, which come from China and southeast Asia.

In air-air heat pumps, the lower cost end of the market (of the order of 20%) are made in Asia, with the mid- and higher end of the price range made in the EU. Large air-air heat pumps are typically manufactured in Europe, in particular in Italy and Spain as climate control for large buildings. Exhaust air heat pumps are also mainly manufactured in Europe.

Air-water heat pumps are generally assembled in Europe. The components of the inside unit are more often manufactured in the EU than those of the outside unit (fan, heat exchanger, housing). Ground-water heat pumps and large air-water heat pumps also tend to be assembled in Europe, but with more European components. Domestic hot water heat pumps are both imported and manufactured in the EU, in roughly equal shares. Absorption heat pumps, mainly for DHC and industrial applications, are vertically integrated, i.e. manufactured and assembled in Europe.

General barriers to imports also apply to heat pumps, and general characteristics of the buildings sector apply also to heat pumps; these represent a strength from the perspective of EU manufacturers. For example, renovation and construction, and networks of tradespeople, are highly local – it is difficult to achieve

[36] Depending on the source, market size can be measured in terms of turnover or production value. Production value measures the amount actually produced, based on sales, including stock changes and resale. Turnover corresponds to market sales; it includes all duties and taxes with the exception of VAT.

[37] The CE Delft calculation is based on PRODCOM and other sources as part of a forthcoming study carried out on behalf of the JRC. The JRC calculation is based on UN Comext data for 2021 as part of the CIndECS study (forthcoming 2023).

European scale, let alone global. Moreover, siting of manufacturing depends on factors such as local (i.e. national) demand for the products in question, local economic growth, availability and cost of labour, government incentives to industry in general, tax structures, distance to market in the case of exports, etc.

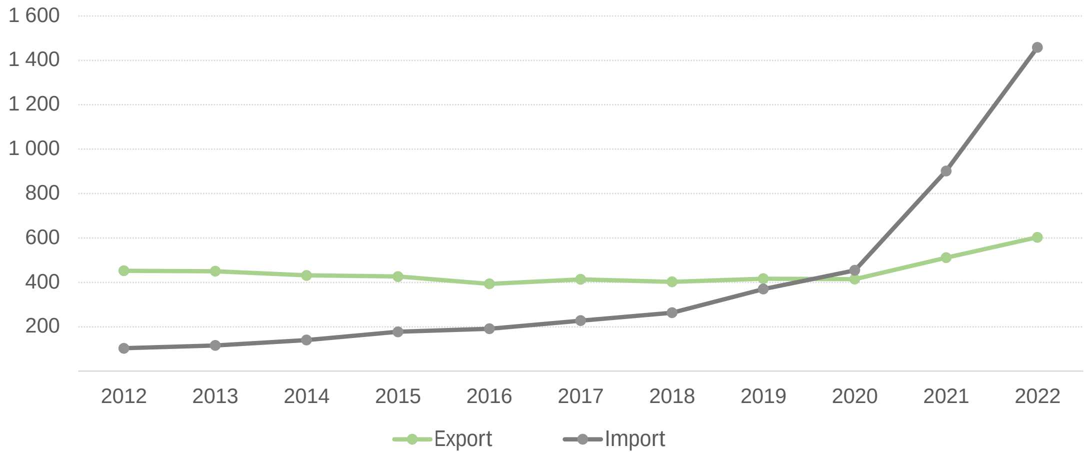
The negative impact of distance on heat pumps trade increased significantly between 2017 and 2022 (CER, 2023). In the very long term (2030s and 2040s), perhaps exports will become relatively more important to EU manufacturers if some EU markets reach high levels of deployment (saturation effect).

In industrial heat pumps, Europe (including Switzerland) and Japan are the technology leaders. Some EU companies focus on domestic markets but others include non-EU markets in their portfolios. Some deliver turnkey projects, including outside the EU, while others sell and export components (using international service and maintenance networks).

4.3 Trade

In 2020 the EU trade balance for heat pumps turned from a surplus to a deficit for the first time, as a result of increasing imports; exports also rose but more slowly (Figure 28). The trade deficit more than doubled to 856 million in 2022 compared to 2021, from a surplus of EUR 186 million five years previously. This increase is particularly stark, but it is also part of a broader trend seen across manufacturing categories during the period; a trend that seems to have been weakening during 2023.

Figure 28. Extra-EU exports and imports, 2013-2022 (EUR millions)

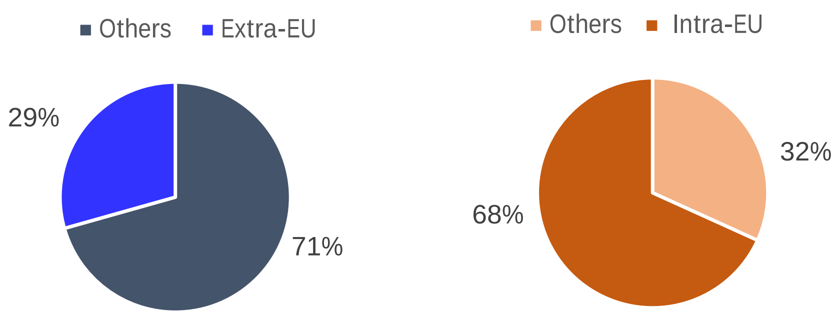


Source: JRC based on COMEXT, code 841861, mainly-heating heat pumps.

Notes: Data may be reported in COMEXT and UN Comtrade with differences in methodology, which for certain countries (e.g. the Netherlands) are significant. The level of inconsistency introduced depends on how active the country is in the value chain. Most charts rely on a single source to eliminate this effect. EU exports/imports are less than the sum of individual Member State imports/exports because it is calculated for the EU as a whole (i.e. subtracting intra-EU trade).

The EU has a strong presence in global trade as extra-EU exports accounted for 29% of world exports during 2020-2022. Over the same period, 64% of imports by Member States came from other Member States (Figure 29). The biggest destinations for extra-EU exports were Switzerland and the UK.

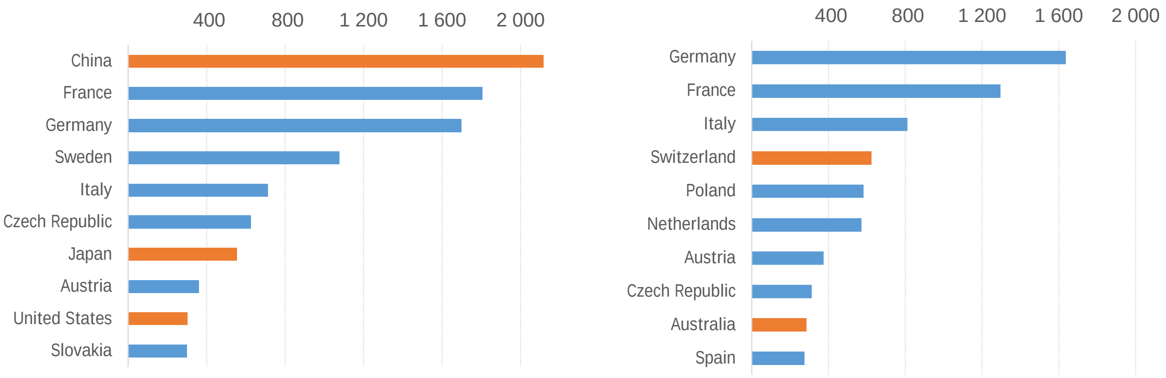
Figure 29. Extra-EU share in world exports (left) and Member State imports (right), 2020-2022



Source: JRC based on COMEXT, code 841861, mainly-heating heat pumps.

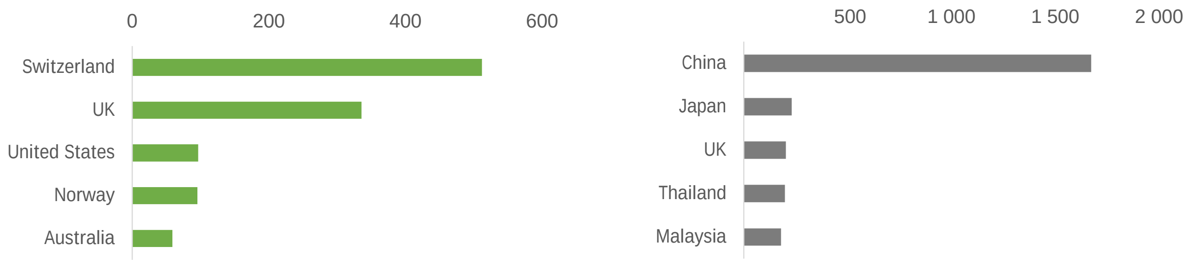
China is now the top exporting country by value over the period 2020-2022, when comparing against individual Member States (Figure 30 left). Imports from China to the EU have seen very fast growth in the last few years, reaching EUR 1.7 billion in 2022 (Figure 31 right). France, Sweden and the Czech Republic are the Member States with the most positive trade balances in absolute terms (Figure 32 left).

Figure 30. Top ten exporting (left) and importing (right) countries worldwide, 2020-2022 (EUR millions)



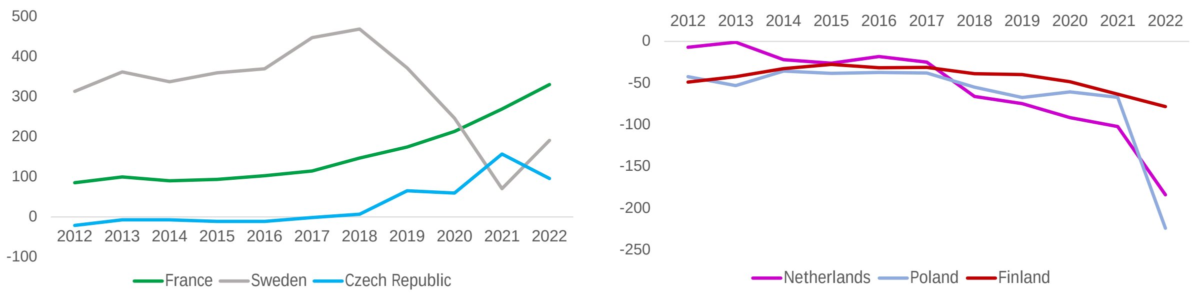
Source: JRC based on COMTRADE, code 841861.

Figure 31. Top five importers from the EU (left) and exporters to the EU (right), 2020-2022 (EUR millions)



Source: JRC based on COMEXT.

Figure 32. Top three Member States by positive (left) and negative (right) trade balance, 2012-2022 (EUR millions)



Source: JRC based on COMEXT, code 841861.

There is a concern that large manufacturers of air conditioners who can produce equipment at low cost, especially ones based in Asia and North America, will turn their attention to capturing the EU heat pump market. There are about 3 billion air conditioning units installed worldwide already, and demand is projected to grow strongly (Mitsui & Co., 2023). This may already be happening in reversible air-air heat pumps, for which the EU is more dependent on imports, and in air conditioners themselves, for which the market in Europe is also growing fast (Financial Times, 2022). Nevertheless, heat pumps rely on the expertise and recommendations of local networks of installers, and growth in demand for air conditioning also represents an opportunity for innovation and economies of scale in reversible heat pumps that provide both heating and cooling.

Imports from China in particular have been rising for the past three years but from a low base and in a context of very rapid deployment overall. EU manufacturing capacity is expanding rapidly, and extra-EU manufacturers may decide to create subsidiaries in the EU or acquire EU manufacturers, rather than export into the market. This has already been happening, notably with the recent acquisition of Viessmann by Carrier. There may also be intra-EU consolidation to reap economies of scale in a similar way.

From the perspective of large incumbent manufacturers (mostly based in Germany, Italy and France), some of whom also manufacture gas and oil boilers, the entry of manufacturers from outside the EU could be seen as a threat. They could compete in the heat pumps market directly and also accelerate the overall speed of the transition away from gas boilers (which are lower margin but where is also less competition from outside the EU) and towards heat pumps.

New entrants via acquisitions or creation of subsidiaries would bring capital investment, innovation and economies of scale for the ecosystem (components, distribution, etc.) in the medium term. Conversely, protectionist industrial policy could create reliance on large incumbents from e.g. Germany, Italy and France, reducing innovation and competitive pressure overall in the EU.

Unit costs depend on raw materials, labour, energy, taxes, credit, marketing, installation and other costs. The cost of manufacturing heat pumps in a given location is comparable to that of similar heating systems, appliances or equipment.

Distance to market and component supply are also important factors in international competitiveness. Several Asian manufacturers of heat pumps have already set up subsidiaries in the EU, including market and manufacturing, and some have acquired EU-headquartered companies.

Competitors from other sectors can be expected to enter the heat pumps market. For example, Chinese manufacturers of large solar collectors are expanding into heating more broadly, with half of them offering stand-alone heat pumps and solar heat pump systems (REN21, 2022). Both China and the United States are implementing policies to support heat pumps, for export as well as for supplying their domestic markets.

At the component level, compressors for air-air heat pumps are largely imported from China, either as part of the product or a prefabricated refrigeration cycle. This development seems to have occurred within the past decade. Most compressors for air-water and ground-source heat pumps are still sourced in Europe.

According to PRODCOM,[38] the quantity of compressors used for refrigeration equipment produced in the EU decreased by 30% between 2008 and 2020.[39] Domestic production has been replaced by imports, which grew by 44% over the same period.[40] Trade and production data suggest that the focus of EU companies shifted to higher value segments.[41]

[38] PRODCOM code 28132300: Compressors for refrigeration equipment and the corresponding HS code 841430.
[39] Production value in monetary terms dropped by 16% over the same period.
[40] Production value in monetary terms dropped by 38% over the same period.
[41] EU export quantity decreased by more than 30%, while export value increased by 8%. Based on trade and production data from PRODCOM, EU unit prices in 2008 were about the same as import prices, whereas in 2020 EU unit prices were 30% higher than those of imported units.

5 Opportunities and challenges

5.1 Environmental

In all Member States, ground-source heat pumps have lower emissions than gas boilers. For air-water boilers, the same is already true everywhere except Poland and Estonia. The ongoing decarbonisation of electricity means that heat pumps will outperform boilers by 2030 even in those two countries, thus offsetting the additional emissions of a heat pump installed today through savings later in its lifespan (Cool Products, 2021).

Today's heat pump stock in Europe avoids 52 $MtCO_2$ (EHPA, 2023a). Toleikyte et al. (2023) find that replacing 30 million fossil boilers with heat pumps under REPowerEU would reduce the CO_2 emissions of those buildings by 28% by 2030.

Heat pump technology is identified by the Strategy for Energy System Integration as a key technology to decarbonise space heating and domestic hot water production, as well as cooling for buildings and industry. The heat pump sector is already the biggest contributor to the increase in renewable energy production for heating and cooling across the EU.

There are energy efficiency requirements on space heaters and domestic hot water under the Ecodesign Regulation (product groups known as ENER Lots 1 and 2). In parallel, energy labelling provides information to consumers on their energy performance (and other environmental parameters).[42] These rules have led to substantial energy savings for consumers already.

The rules are now being reviewed to take account of technological progress in the sector, ease comparison across different product types, and use an A to G scale. The revision process is ongoing but has been given renewed impetus as a consequence of the REPowerEU and EU Save Energy plans. The proposal implies an end date of 2029 for fossil boilers being placed on the market. Some Member States are implementing bans earlier than that (ECOS, 2023).

There is also a revised ENER Lot 10 (which includes air-air heat pumps), expected to kick in from 2025 with possibly new test methods from 2027; and Lot 21 (larger air heating products) will have new energy efficiency thresholds and test methods probably by 2030 (EHPA, 2022).

Heat pumps reduce nitrogen oxides, sulphur oxides and particulate matter emissions relative to boilers, improving indoor and outdoor air quality and entailing important health benefits. Some types of heat pump can make an additional contribution to indoor air quality by providing ventilation and filtering services as well. This is an important driver in China but outdoor air quality in Europe is also below World Health Organization standards.

Several LCA studies of heat pumps exist; Viessmann (Germany) recently published its first third-party verified LCA of an air-water heat pump for the French market, in compliance with that country's ecopassport legislation (EVEA, 2023). There are values for the bill of materials in the widely used software SimaPro, and the Institute of International Refrigeration has published guidelines for Life Cycle Climate Performance too (IIR, 2016).

As is the case for boilers, the use phase of a heat pump (in this case electricity consumption) dominates its life-cycle emissions, followed by refrigerant (approximately 14%). The carbon intensity of electricity used in Ecodesign preparatory studies is 384 g/kWh (VHK and BRG, 2019).

Natural refrigerants can have unfavourable toxicity characteristics. F-gases on the other hand are PFAS (per- and polyfluoroalkyl substances) and may be significantly affected by future PFAS regulations and REACH. They are also subject to restrictions on hazardous substances due to the RoHS Directive. PFAS are also used in heat pumps in electronic components, plastics and coatings.

Heat pump lifespan is between 10 and 30 years with a typical value of 17 years, compared to typical boiler lifespan of 20-25 years (ECOS, 2023). The ground loop in a ground-source heat pump system can have a useful life of 50-100 years. In life-cycle assessment (LCA), lifespan can be an important factor in comparing types of heat pump or in comparing heat pumps with alternative renewable heating systems such as solar thermal (Litardo et al., 2023). Lifespans of industry heat pumps can be more than 35 years (MAN Heat Pump – DBDH, 2023).

[42] In Germany, there is a proposal to reissue a Blue Angel eco-label for domestic heat pumps (Becker et al., 2022).

Metals can and should be recycled, and the circularity of heat pumps could be improved with better reparability and modular design (EC, 2021a). Refrigerant can also be reused, bearing into account that some will have leaked over the lifetime of the heat pump. Leakage ranges from 1.5-5% per year; 2% leakage over 17 years for example would represent a total loss of 28%.

Heat pumps are within the scope of the 2012 Waste from electrical and electronic equipment Directive, which required Member States to achieve a recovery rate for heat pumps of 85% by August 2018, and a reuse/recycle rate of 80% (VHK and BRG, 2019). Temperature exchange equipment, which includes heat pumps, is already the fastest growing category of e-waste worldwide (Forti et al., 2020), and roughly 15% of used electrical and electronic equipment is exported from the EU, mainly for reuse (Bio Intelligence Service in Alfieri and Spiliotopoulos, 2023).

5.2 Socio-economic

Heat pumps, perhaps more than other technologies, play a direct role in the competitiveness of the economy (households, businesses and public organisations) by reducing the level and especially the volatility of energy bills. Even more so when combined with self-generation such as solar PV and a home energy management system, or deployed as part of DHC.

Lower-income households benefit most from adoption, through lower energy bills. In that way, targeted heat pump deployment can form part of a strategy to address energy poverty. Crucially however, up-front costs and the tenant-landlord problem are often insurmountable barriers that need to be addressed.

Energy efficiency measures reduce the risk of mortgage default, through lower energy bills. Heat pumps should have a similar effect. This raises the opportunity for green mortgages or other concessional lending to address the up-front investment barrier. It is also important to note that heat pump owners can benefit from a premium on their property value. In the United States, this has been found to be 4.3-7.1% on the sale price for an air-source heat pump (Shen et al., 2021). That is substantially more than either the cost of switching or the longer-term economic savings.

Social barriers to take-up may include noise, visual impact and space requirement. Immediate neighbours might object on those grounds too. Therefore, these are important areas for research and represent one way that heat pumps can contribute to the New European Bauhaus (Box 6).

Box 6. Heat pumps and the New European Bauhaus

The New European Bauhaus (NEB) is an initiative by the European Commission to make living spaces sustainable, inclusive and beautiful, leading to a better quality of life for citizens. Commission President Von der Leyen referred to this initiative as the “soul” of the European Green Deal, and thinking about heat pumps along these lines can be an important way to stimulate deployment.

The definition of “beautiful” should be interpreted broadly, to include aesthetic considerations (the heat pump itself and its placement) but also aspects such as comfort and noise. Space limitations, for example, are being addressed through rooftop placement, boreholes for ground-source heat pumps, and better component integration within the heat pump housing. There has been a trend in the market towards quieter heat pumps. And manufacturers are also trying to improve the aesthetics of the device itself, e.g. Daikin has a “Stylish” range and several other manufacturers use alternative materials or colours.

The inclusive or “together” principle is of most relevance when considering heat pumps in DHC, but can also refer to street or neighbourhood approaches to deploying individual systems, such as in the context of social housing, shared ground loops at street level for ground-source heat pumps, or large heat pumps for apartment buildings. Citizen engagement and co-design should be encouraged at all levels, and collective purchase campaigns could be envisaged. In the EU-funded Clear 2.0 and CLEAR-X projects for example, national consumer organisations facilitated collective purchase of PV panels and heat pumps. More organically, households might be more likely to install a heat pump if they see one installed nearby, as was seen with rooftop solar.

“Sustainability” is of course a particular strength of heat pumps relative to fossil alternatives. Nevertheless, this principle should also push the sector to consider broader sustainability aspects such as circular economy, and to take into account the full life cycle.

For example, heat pumps also contribute to sustainable neighbourhoods by obviating the need for fuels delivery by truck or for gas distribution infrastructure. They are particularly well suited to more rural or peri-urban neighbourhoods, where DHC may not be feasible, or where there is a large share of detached housing for which certain constraints may be less pressing, e.g. noise, space for external units, land for geothermal drilling.

The NEB initiative is covered by nine EU programmes (Horizon Europe, ERDF, LIFE, Digital Europe, Single Market Programme, COSME, Erasmus+, Creative Europe and the European Solidarity Corps. There is also a proposal to develop it as a Mission under Horizon Europe. In the meantime, further examples of heat pump projects that may contribute to the NEB can be found as part of the Heat Pump Award of the EHPA.

Sources: NEB initiative (new-european-bauhaus.europa.eu); Motoasca et al., 2023; BEUC, 2023; hpa.ehpa.org.

From a social perspective, safety and cybersecurity concerns are sometimes raised with regard to heat pumps. Propane and other hydrocarbons are flammable and this needs to be considered carefully at the design stage, both for the products themselves and their manufacturing facilities. International safety standards are in place and being improved on an ongoing basis. New standards with more detailed safety precautions would allow more widespread use of hydrocarbon refrigerants. Improved safety is also an important benefit of DHC, by providing a further degree of separation.

An important factor for increasing safety or broadening the use of hydrocarbons to larger heat pumps is to reduce the refrigerant charge per kW capacity. This has been neglected until now since the amount of charge is not an important factor when using non-flammable fluids. RD&I has shown that efficient systems can be operated with about 10 g of propane per kW, compared to about 100 g of propane/kW with typical designs (ATMOsphere, 2023a).

Heat pumps represent a low systemic risk for cybersecurity as a decentralised technology but smart controls may represent a risk vector. From the societal perspective, the safety and cybersecurity risks of alternative heating systems, both individual and collective, should also be considered.

Fom the manufacturers' perspective, digitalisation represents an opportunity to capture additional value and profits from EU households and businesses, and protect themselves from competitors within and outside the EU, including from related sub-sectors in the digital or buildings domains. Standardisation and interoperability are important ways to spread this benefit across society. DG Energy and the JRC have proposed a Code of Conduct to energy-smart appliance manufacturers in this regard[43] and there is also a European framework for sharing energy data in development.

More generally, heat pumps are made from relatively common raw materials, with few heat pump-specific components, and relatively straightforward assembly. There is also nothing very different from similar EU manufacturing sectors in terms of water consumption, energy, processes, labour costs, etc. Therefore, the transition should not be excessively disruptive to industry in aggregate.

5.3 Energy security

Heat pump deployment reduces dependence on fossil fuels, mainly gas imports. Heat pumps, and related technologies such as boilers and air conditioners, are mass produced in large volumes around the world. Their "fuel" is ambient or geothermal energy and electricity. These factors mitigate the economic risk and potential cost of a supply disruption.

Grid capacity needs to be considered, at the level of the transmission grid and also locally in distribution, when an entire apartment building or neighbourhood switches to heat pumps. Utilities say that a roll-out of 50 million heat pumps by 2030 will not jeopardise grid stability if grids are upgraded and demand-side flexibility is exploited (aeléc et al., 2021).

Modelling by Toleikyte et al. (2023) finds that 30 million additional hydronic heat pumps will bring heat pumps' share of grid demand to 18% during the peak morning hours of a cold winter day. That should not cause any major issues for the grid in 2030 at transmission level. This moderate impact can be further alleviated through the integration of smart controls, or by increasing the COP of the heat pump stock, for example through a greater share of ground-source heat pumps. However, potential issues at distribution level also need to be assessed and addressed, and this is the subject of ongoing research.

[43] See https://ses.jrc.ec.europa.eu/development-of-policy-proposals-for-energy-smart-appliances.

Heat pumps can provide demand response and they can be combined with thermal storage (including the mass of the building), smart controls and solar PV in a "comfort and climate box" (IEA HPT, 2022). Therefore, once grid capacity continues to accommodate deployment, heat pumps can actively contribute to grid stability.

In addition, a large part of the electric load is from electric heating during winter in a few countries: if electric heating is replaced in these countries by heat pumps, the peak load gain could be significant. There may also be significant savings at macroeconomic level if high gas prices persist (DIW, 2022).

The amount of flexibility provided by a heat pump varies by type (hybrid or electric), building characteristics (size, insulation), etc. The share of internet-connected heat pumps is assumed to rise from 23% today to 95% in 2050 under a REPowerEU-inspired scenario.

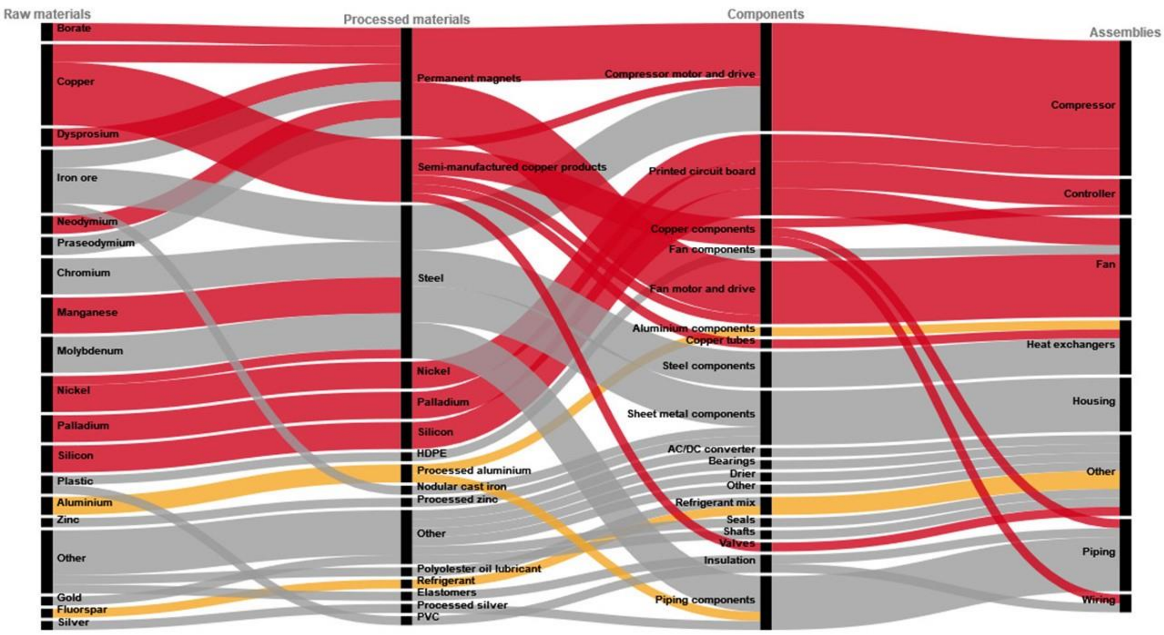
Additional grid investments will in any case be needed, in line with rising electricity consumption across the economy, including from electric vehicles and process electrification. Conversely, there may be investments in gas infrastructure that do not materialise. Nevertheless, grid investment plans need to be delivered on time, and particular attention should be paid to the distribution network and in-building electrical installations.[44]

Heat pumps have a higher power load than other residential appliances. They have to be connected through dedicated circuits, which requires additional attention to safety. Therefore, the electrical works must be installed by an electrician or other qualified person (FEEDS, 2020). As a high proportion of EU dwellings have obsolete electrical installations, this is also an opportunity to address any other safety issues.

5.4 Resource efficiency and dependence in relation to EU competitiveness

Heat pumps are manufactured from similar raw materials to the boilers they replace, and hydronic heat pump systems have comparable plumbing systems to boilers as well. 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 (Figure 33).[45]

Figure 33. Heat pumps materials, components and assemblies



Source: Raw materials categories based on Carrara et al., 2023.
Notes: Red = Strategic Raw Material. Orange = Critical Raw Material. HDPE = High-density polyethylene. PVC = Polyvinyl chloride. This chart is for illustrative purposes and the supply chain varies depending on heat pump type and model.

[44] Heat pumps are far from the only challenge to be faced by distribution (and transmission) systems over the coming decade. See for example www.edsoforsmartgrids.eu/latest-news/e-dso-publishes-its-technology-radar.
[45] Chile is the leading copper-producing country worldwide, with Poland leading in the EU.

More widespread integration of smart controls might exacerbate the vulnerability to semiconductor shortages, but smart controls are also necessary in order to maximise 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 speed of the pump 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 at small scale or in the context of research projects.

Permanent magnets are a potential supply risk because there are few short-term solutions to a disruption to imports from China.[46] There is also a risk of non-compliance through using less efficient motors that do not contain permanent magnets.[47] 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.

By weight, the representative air-source heat pump in Table 5 consists of 72% steel of various types, 17% copper, 7% elastomers, 3% refrigerant and lubricants, and 1% plastic. The air-water heat pump in the Viessmann LCA consists of 58% steel, 7% copper, 21% other metals, 4% plastic, and 9% other materials, for a total mass excluding packaging of 239.8 kg (EVEA, 2023).

Table 5. Bills of materials of an air-source heat pump and a gas boiler, each with a capacity of 10 kW (kg)

	Air-source heat pump	Gas boiler	Difference
Reinforcing steel	120		120
Copper	36.6	3	33.6
Low-alloyed steel	32	115	-83
Elastomers	16		16
Stainless steel	5	5	0
Refrigerant (R134A)	4.9		4.9
Polyolester oil	2.7		2.7
PVC	1.6		1.6
HDPE	0.5	0.9	-0.4
Rockwool		8	-8
Aluminium		7.5	-7.5
Brass		0.1	-0.1
Total	219.3	139.5	79.8

Source: JRC based on Greening and Azapagic, 2012.

Notes: HDPE = High-density polyethylene. PVC = Polyvinyl chloride.

Compared to a representative gas boiler, the heat pump uses a greater quantity of copper, some additional materials, and notably a refrigerant. Materials intensity and refrigerant charge have fallen marginally over time and should continue to do so.

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

[46] Alternatives may emerge in future, e.g. Vietnam, see www.reuters.com/markets/commodities/rare-earths-magnet-firms-turn-vietnam-china-hedge-2023-08-22.

[47] There is also a risk of non-compliance through using less efficient motors that do not contain permanent magnets. See for example https://constructionmanagement.co.uk/pump-industry-warns-about-non-compliant-heating-pumps-surge.

6 Conclusions

Sales of heat pumps grew very rapidly during 2021 (+34%) and 2022 (+39%). However, maintaining such growth rates will be challenging. There are a number of potential bottlenecks and barriers in the short term, such as a shortage of semiconductors and a lack of qualified installers and experts.

Boiler installers can be trained but this needs to be made a priority to ensure a smooth transition. A dedicated new partnership on heat pumps under the Pact for Skills could help. In the longer term, greater focus on education and training in all related technical fields is needed, and it could also be worth examining why such labour shortages are more acute in some Member States and whether there are barriers to mobility that could be alleviated.

Heat pumps have few specific materials vulnerabilities. They are however vulnerable to general volatility in metals prices and semiconductors supply. Heat pump deployment could benefit from consideration as an important product category in responding to those issues.

The electricity grid is expected to be able to cope with up to 50 million heat pumps under the usual network investment plans. Moreover, heat pump systems should be designed so as to contribute to grid stability. Nevertheless, grid investment plans need to be delivered on time, and particular attention should be paid to the distribution network and in-building electrical installations.

Bottlenecks are often not specific to heat pumps: components are similar to those found in boilers, air conditioners or refrigeration; metals prices and chip shortages are economy-wide issues; the pool of workers is shared with related technologies and sectors. Both broad and narrow policy responses are needed.

The heat pumps sector is well positioned to benefit from increasing deployment. Imports from China have however increased in recent years. Both China and the United States are implementing policy to support heat pump deployment and their heat pump manufacturing, domestic including for export. Long-term policy ambition and supportive regulations are important in order to promote investment in EU manufacturing too.

Incentives to manufacturers to invest in new production lines, or convert existing production lines from gas boilers to heat pumps, would increase production capacity faster. An analysis of potential barriers to trade in the internal market (e.g. insufficiently ambitious building codes or disparate certification requirements) could also help improve the competitiveness of EU manufacturers by exploiting economies of scale; the EU heat pumps sector is still somewhat fragmented and national laws and requirements differ.

In the short term, some stakeholders see F-gas phase-down as a limiting factor. However, in the medium term, the transition to greater use of natural refrigerants can be an opportunity for the sector to differentiate itself with respect to non-EU competitors and to reduce dependence on non-EU suppliers.

The EU is the world leader in innovative heat pump technologies and related patenting activity. It is important to boost collaborative RD&I funding to continue to drive down costs and enable new business models based on products that are easier to install and operate. By maintaining its technology leadership, EU manufacturing will be well placed to adapt to, and benefit from, market developments such as ecodesign requirements and the shift to natural refrigerants.

Finally, tracking exercises such as this one rely on publicly available and transparent data. Member States should continue to invest in the timeliness, completeness and quality of statistics on topics such as energy, markets, costs and RD&I, both via their national statistics offices and Eurostat. For example, Estonia reported a 7.5% increase in its share of renewables for heating and cooling in 2021 because it started to report the use of heat pumps for the first time (Eurostat, 2023b).

Although this report has not focused on the policy perspective, the following recommendations can be made to strengthen the heat pump supply chain:

– Statistics at national and Eurostat levels should be improved to track and monitor this fast-moving market.

– Public investment in heat pump RD&I is currently at very low levels relative to other technologies and an urgent increase is required. Although heat pumps are a mature technology, further investment is needed in areas such as reduction of up-front costs, increased efficiency, new business models, and solid-state technologies.

- The prioritisation of heat pumps in work on standardisation and interoperability would increase their attractiveness to households, ensure a level playing field, and maximise system benefits from flexibility. Deployment would be further enabled through greater international alignment of such standards.
- While heat pumps are promoted as a key technology, it is important to continue to maintain high ambition across related energy policy areas including district heating and renovation for improved energy efficiency.

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List of abbreviations

AC/DC	alternating current / direct current
AREA	Air conditioning and Refrigeration European Association
AT	Austria
BE	Belgium
BEUC	Bureau européen des unions de consommateurs
BG	Bulgaria
CAPEX	capital expenditure
CETO	Clean Energy Technology Observatory
CINDECS	European Climate-Neutral industry Competitiveness Scoreboard
CINEA	European Climate, Infrastructure and Environment Executive Agency
CO_2	carbon dioxide
COP	coefficient of performance
CPC	Cooperative Patent Classification
CY	Cyprus
CZ	Czech Republic
DC	direct current
DE	Germany
DG	Directorate-General
DHC	district heating and cooling
DK	Denmark
EC	European Commission
EE	Estonia
EEA	European Environment Agency; European Economic Area.
EGEC	European Geothermal Energy Council
EH&P	Euroheat & Power
EHI	European Heating Industry
EHPA	European Heat Pump Association
EL	Greece
ENER	DG Energy
EPEE	European Partnership for Energy and the Environment
EPO	European Patents Office
ES	Spain
EU	European Union
F-Gases	fluorinated gases
FEC	final energy consumption
FI	Finland
FR	France
GW	gigawatt

GWh	gigawatt-hour
GWP	global warming potential
HDPE	High-density polyethylene
HR	Croatia
IE	Ireland
IT	Italy
JRC	Joint Research Centre
kW	kilowatt
kWh	kilowatt-hour
LCA	Life-Cycle Assessment
LT	Lithuania
LV	Latvia
m^2	square metre
m^3	cubic metre
Mtoe	million tonnes of oil equivalent
MW	megawatt
MWh	megawatt-hour
NECP	National Energy and Climate Plan
NL	Netherlands
PFAS	per- and polyfluoroalkyl substances
PL	Poland
POTEnCIA	Policy Oriented Tool for Energy and Climate Change Impact Assessment
PRODCOM	Eurostat database of the production of manufactured goods
PT	Portugal
PV-T	photovoltaic-thermal
PVC	polyvinyl chloride
RD&I	research, development and innovation
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals (EU Regulation)
RED	Renewable Energy Directive
RHC Platform	Platform on Renewable Heating and Cooling
RTD	DG Research and Innovation
SCOP	seasonal coefficient of performance
SE	Sweden
SET-Plan	Strategic Energy Technology Plan
SI	Slovenia
SK	Slovakia
SME	small and medium-sized enterprise
SPF	seasonal performance factor
TRL	Technology Readiness Level

UK	United Kingdom
VAT	value added tax

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Annex: POTEnCIA 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 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:

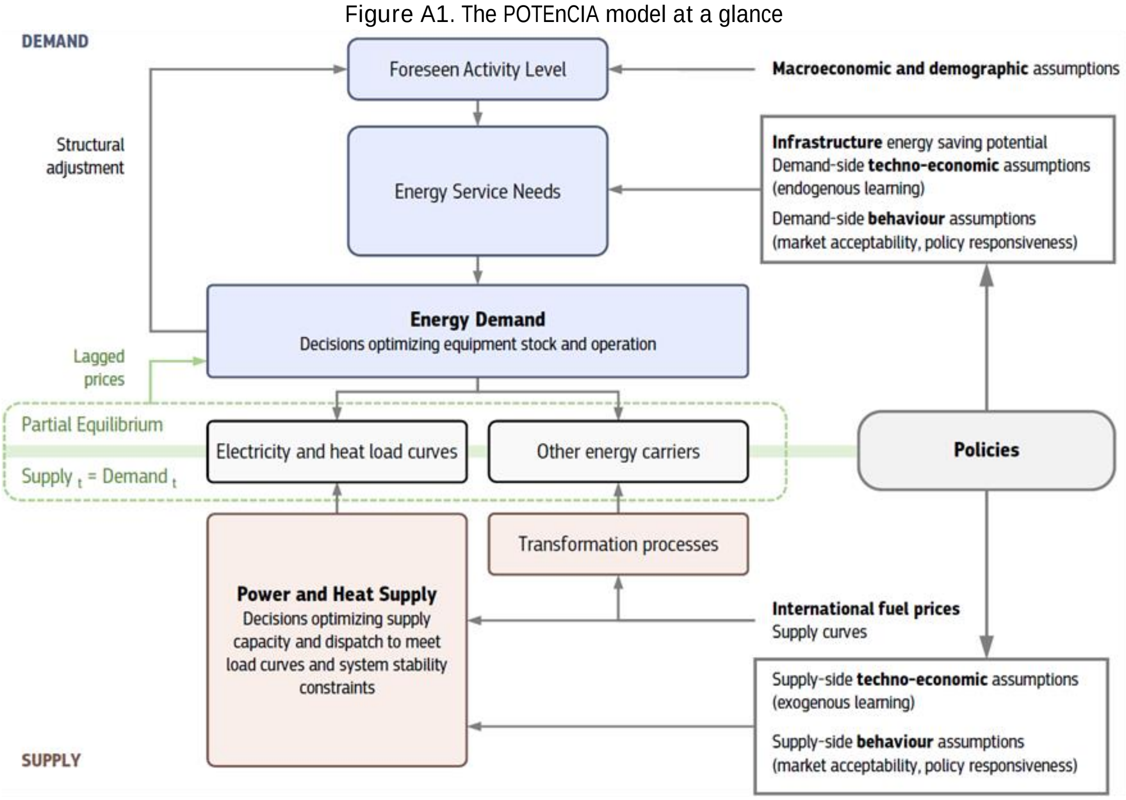
— By simulating decision-making under imperfect foresight at a high level of techno-economic detail, POTEnCIA realistically captures the adoption and operation of new energy technologies under different policy regimes;

— 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 A1; detailed in the POTEnCIA model description[48] and in the POTEnCIA Central Scenario report[49]) 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 maximise its benefit or minimise its cost under constraints such as available technologies and fuels, behavioural preferences, and climate policies.

Figure A1. The POTEnCIA model at a glance



Source: Adapted from the POTEnCIA Central scenario report.

This core modelling approach is tailored to each sector, for instance to represent different planning horizons and expectations about future technologies under imperfect foresight. In particular, power dispatch modelling uses a high time resolution with full-year hourly dispatch to suitably depict the increasing need for flexibility

[48] https://joint-research-centre.ec.europa.eu/system/files/2017-10/potencia-new-eu-wide-energy-sector-model-working-paper.pdf.
[49] https://publications.jrc.ec.europa.eu/repository/handle/JRC118353.

from storage and demand response, and the changing role of thermal generation in a power system dominated by variable renewable energy sources.

Within this sector modelling framework, investment decisions of the representative agents are simulated with discrete-choice modelling. The model then finds an overall equilibrium across different sectors using price signals for resources such as traditional and renewable energy carriers while accounting for efficiency and environmental costs.

This core modelling approach is implemented individually for each 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).[50] JRC-IDEES has been developed in parallel to POTEnCIA, and an updated release is planned in 2024 to ensure the transparency of POTEnCIA's base-year conditions and to support further research by external stakeholders.

POTEnCIA CETO Climate Neutrality Scenario overview

The technology projections provided by the POTEnCIA model are obtained under a Climate Neutrality Scenario aligned with the broad greenhouse gas reduction objectives of the European Green Deal. As such, this scenario reduces net EU-27 emissions by 55% by 2030 versus 1990, and reaches EU-27 climate neutrality by 2050 under general assumptions summarised in Table A1. To suitably model technology projections under these overarching targets, the scenario includes a representation 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 deployment of bioenergy and renewable power generation technologies to 2030 is consistent with the EU's Renewable Energy Directive target (42.5% share of renewables in gross final energy consumption by 2030).

Table A1. General assumptions of the POTEnCIA CETO Climate Neutrality Scenario

General scenario assumptions	Modelled scenario and policy assumptions
GDP growth by Member State	GDP projections based on EU Reference Scenario 2020, with updates to 2024 from DG ECFIN Autumn Forecast 2022
Population by Member State	Population projections based on EU Reference Scenario 2020, with updates to 2032 from EUROPOP 2019
International energy markets	Natural gas import projections consistent with REPowerEU targets for supply diversification and demand reduction. International fuel price projections to 2050 aligned with REPowerEU

Source: JRC.

[50] https://publications.jrc.ec.europa.eu/repository/handle/JRC112474.

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