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The Heat Pump Wave: Opportunities and Challenges

Analysis of the largescale deployment of heat pumps by 2030 following the REPowerEU plan

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Abstract

Decarbonisation of heating is a key priority of the EU's climate agenda, given that the building sector is responsible for 36% of total greenhouse gas emissions. Heat pumps play a central role in enabling the transition towards a climate-neutral society, and are also seen as a crucial tool in achieving independence from foreign oil and gas sources. The EU has set out a plan to quickly ramp up the manufacturing and installation of heat pumps. This study examines the potential impacts arising from this scale-up of heat pump installations.

The European Building Energy Model (EBEM), an in-house bottom-up building model, has been developed to analyse current and future energy trends based on disaggregated building stock. The model accurately estimates and compares specific energy consumption and CO_2 emissions, taking into account parameters such as heating type, insulation level and climatic region.

The analysis shows that replacing 30 million fossil fuel individual boilers in residential dwellings with heat pumps would reduce the EU's gas and oil consumption by 36% in these dwellings. In the large majority of cases, switching from a fossil fuelled boiler to a heat pump will result in lower bills for heating. While the additional heat pumps will deliver more stress to the power grids, the impact is relatively modest and can be reduced, or even alleviated, by activating demand-side flexibility measures.

The study also concludes that a rapid scale-up of heat pumps will require more and higher skilled workers across the whole value chain. The EU's heat pump supply is chain is vulnerable in a few areas, including a large dependence on imported compressors and semiconductors. Furthermore, there is a clear risk of financially vulnerable groups being excluded from this transition without targeted financial support.

Finally, the EU is currently a leader in the production of several heat pump segments, but competition from American and Asian companies, particularly China, is rapidly increasing. Nevertheless, the EU is well placed to benefit economically from increased focus on heat pumps.

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Executive summary

The European Commission launched the REPowerEU plan in 2022 to make the EU independent of Russian fossil fuels well before 2030. As the natural substitute to gas and oil boilers, heat pumps play a central role in achieving this objective. The plan sets out to install 30 million heat pumps, mostly hydronic, by 2030, thereby catalysing a significant transformation of Europe's heating and cooling sector. This analysis looks at the implications of the largescale deployment of residential heat pumps. Various aspects of this transition are discussed, including the potential of various types of building for heat pump installation, the impact on the power grid and the competitiveness of heat pump manufacturers, as well as barriers such as a lack of skilled installers, supply chain constraints, the availability of environmentally friendly refrigerants and the risk of negative effects on vulnerable households.

The heating of buildings is central to the EU's climate policies, as nearly 40% of final energy consumption and 36% of greenhouse gas emissions stem from buildings. Many of Europe's buildings are old and inefficient, with over 40% of the building stock constructed before 1960 and 90% before 1990, prior to the implementation of stringent efficiency regulations. Furthermore, a significant proportion of space heating still relies on fossil fuelled heat sources, mainly natural gas, but also oil and coal. This analysis examines the opportunities and challenges associated with replacing oil and gas boilers with heat pumps, including the implications for the EU.

In 2021, heat pumps accounted for a market share of 21.5% of all sold heating generators in the EU. However, the market share varied greatly between Member States, with a 96% share in Finland while Germany and the Netherlands had shares of 16% and 13%, respectively (EHPA, 2022). According to preliminary data from the European Heat Pump Association (EHPA), the demand for heat pumps experienced a substantial increase in 2022. Approximately 3 million heat pumps were added in the EU for space heating and domestic hot water, compared to 2.2 million units in the previous year.

Replacing fossil fuel boilers with heat pumps not only offers significant climate benefits but also helps to improve the energy security of the EU. Replacing 30 million oil and gas boilers by 2030 (approximately 35% of the gas and oil boilers) would result in a 36% reduction of the gas and oil consumption in these buildings and a 28% reduction of their CO_2 emissions ([1]). The achieved reductions in CO_2 emissions will increase as the power system undergoes decarbonisation. In countries with a low-carbon power mix, such as Sweden, France, Luxembourg and Finland, the operation of heat pumps is close to carbon-neutral.

Heat pumps work more efficiently when deployed in thermal insulated buildings, although they can often function reasonably well in less efficient buildings, albeit at reduced efficiency level ([2]). The majority of buildings within the EU are old and rather inefficient. Based on our assumptions, around 60% of buildings currently heated by gas or oil boilers should undergo upgrades to ensure high-efficiency operation of the heat pumps. Ideally, it would be deep renovations, however, a partial renovation and/or adjustments to the distributional heating system will also enhance their efficiency. Furthermore, high-temperature heat pumps or hybrid heat pumps can be transitional solutions for buildings with lower performance levels.

European companies still dominate the EU market for heat pumps. However, the most notable increase in imported heat pumps occurred in 2022, with China emerging as the leading contributor. Other large markets, including China and the United States, are actively pursuing strategies to scale up their heat pump deployment, potentially leading to increased competition. Despite this, the EU companies still maintain a strong position by investing in innovation and in adopting new technologies, such as natural refrigerants. One target of the EU Heat Pump Action Plan could be to support the industry in continuing to invest in R&D, to ensure that EU companies maintain their global frontrunner position.

Heat pumps and energy efficiency of buildings are long-term solutions to energy poverty, as the higher efficiencies make the utility bills more affordable. Almost one third of Europeans are unable to face unexpected expenses. Thus, the high upfront cost for heat pumps risks excluding vulnerable households from the clean energy transition. Special support should be aimed at these groups to ensure that heat pumps are successfully rolled out across society.

([1]) Considering the CO_2 emission factors from 2020 for electricity of all EU Member States.
([2]) Contingent on the gas and electricity prices, it is, in many cases, still cost-effective.

Policy context

The EU has implemented a series of actions to decarbonise its building stock. In the European Green Deal, the EU set out a comprehensive plan to make Europe the world's first climate-neutral continent by 2050, by transforming its economy, promoting sustainable growth, and addressing climate and environmental challenges. As part of this plan, the EU established climate protection targets (outlined in the European Climate Law) specifying that by 2030, the EU should achieve a net reduction of 55% in greenhouse gas emissions compared to 1990 levels. Additionally, the EU is committed to attaining climate neutrality by 2050, demonstrating its long-term commitment to mitigating the effects of climate change.

In July 2021, the European Commission announced the Fit-For-55 package outlining measures to achieve the 2030 target, including the revision of several key directives, including the Energy Performance of Buildings Directive (EPBD), Renewable Energy Directive (RED), and Energy Efficiency Directive (EED), as well as comprehensive changes to the EU's emissions trading system (EU ETS). In parallel, the Renovation Wave of the European Green Deal aims to double the energy renovation rates by 2030 from around 1% and promote deep energy renovations. The strategy sets out to renovate 35 million building units by 2030.

The European Commission recently launched the REPowerEU plan to make Europe independent from Russian fossil fuels before 2030. Heat pumps play a significant role in this plan as they provide an obvious alternative to residential fossil fuel boilers. The plan calls for several actions, including the accelerated deployment of heat pumps to substitute fossil fuels for heating, and strengthening European supply chains for heat pump technologies and their components.

The ongoing revision of the EPBD, which addresses the attainment of a highly energy-efficient and decarbonised building stock by 2050, includes several provisions potentially influencing the heat pump market:

— Introduce a minimum energy performance standard (MEPS) for existing buildings, with the objective to trigger renovations of the worst performing buildings. The policy can trigger households to replace the fossil fuel boiler. At the same time, improving the performance of the worst performing buildings would considerably increase the number of buildings in which heat pumps work effectively.

— Support the phase-out of fossil fuels used for heating in buildings. Member States are asked to plan policies and measures to achieve a complete phase out of the use of fossil fuels in buildings out by 2040.

— In all new buildings, where technically feasible, 100% of on-site energy consumption should be covered by renewable energy as of 2030, with an earlier adoption as of 2027 for public buildings.

Under the revised RED, Member States are mandated to ensure the share of renewable energy in the heating and cooling sector increases 0.8 percentage points annually from 2021 to 2025, followed by 1.1 percentage point per year between 2026 and 2030. The share of renewable energy in buildings should reach 49% by 2030.

In 2023, the European Commission presented a Green Deal Industrial Plan. The key pillars of this plan are the Critical Raw Materials Act and the Net Zero Industry Act. While the Critical Raw Materials Act ensures sufficient access to the materials key to manufacturing net-zero technologies, the Net Zero Industry Act provides a regulatory framework for the quick development of net-zero industrial capacity. Heat pumps play a pivotal role as one of the key net-zero technologies emphasised in this act.

Finally, the European Commission is also preparing a Heat Pump Action Plan to facilitate rapid deployment. It sets out four strands of action: (1) partnership between the Commission, EU countries and the sector, (2) communication to all interest groups & a skills partnership for rolling out heat pumps, (3) legislation (EcoDesign & energy labelling), and (4) accessible financing. This plan will be closely coordinated with the Green Deal Industrial Plan and the Net Zero Industry Act, and a part of the wider EU industrial policy push to ensure that "clean" industries are located in Europe ([3]).

([3]) EU Heat Pump Action Plan: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13771-Heat-pumps-action-plan-to-accelerate-roll-out-across-the-EU_en

Main findings

There are approximately 68 million gas and 18 million oil boilers in residential buildings in the EU. The REPowerEU Plan aims to make Europe independent from Russian fossil fuels before 2030. To achieve this goal, renewable energy and energy efficiency measures are to be implemented, for instance installing 30 million new heat pumps. In this study, it is assumed these heat pumps will be replacing existing gas and oil boilers, and that some of the buildings will combine the boiler exchange with envelope renovation. Replacing 1/3 of exiting gas and oil boilers would lead to a reduction of 36% of gas and oil consumption in the affected buildings. This reduction corresponds to 348 TWh of energy saved for residential space heating. In terms of gas consumption alone, replacing 1/3 of the currently existing gas boilers, the EU's residential buildings could save 255 TWh in total of gas, which is approximately 10 billion cubic meters (bcm).

The quantity of gas and oil boilers in residential dwellings varies greatly among Member States, leading to differences in the proportion of installed heat pumps in dwellings for each country. Italy and Germany have the highest number of gas boilers in dwellings, followed by France, Spain, and the Netherlands. Together, these countries make up nearly 75% of the total 68 million gas boilers. As a result, Germany has the potential to achieve the greatest reduction in gas and oil usage, with a potential saving of 125 TWh. France follows with 50 TWh, Italy with 48 TWh, Spain with 22 TWh, and the Netherlands with 18 TWh.

The replacement of a gas boiler with a heat pump can lead to a significant reduction in CO_2 emissions. Depending on the power system configuration, the substitution of a gas boiler with an air-water heat pump has the potential to reduce CO_2 emissions by up to 96%. When considering the residential dwelling stock on a larger scale, our estimation indicates that replacing 30 million oil and gas boilers would result in a reduction of 59 Mt CO_2 emissions. This reduction corresponds to approximately 28% of the current total residential emissions generated by oil and gas ([4]). As electricity generation still largely rely on fossil fuels in many Member States, the opportunity for further savings is substantial.

The analysis indicates that around 41% of all EU dwellings currently heated by gas boilers are properly insulated and that heat pumps can function at high efficiency in these buildings. For almost 60% of dwellings, energy efficiency improvements or adjustment to the heating distribution system (radiators and pipes) should be pursued to ensure heat pumps work efficiently. While heat pumps can also heat less efficient buildings, they typically do so at a lower efficiency.

The efficiency of a heat pump is influenced by two main factors: the temperature of the heat source and the flow temperature of the delivered heat. The flow temperature depends on the hydronic system used. Achieving higher efficiency is easier in well-insulated buildings. In residential buildings with existing oil and gas boilers, hydronic distribution systems typically have maximum flow temperature levels ranging from 55°C to 90°C. However, for a conventional heat pump to operate efficiently, the flow temperatures should be reduced to a certain low-temperature threshold ([5]). To lower radiator temperature, many buildings may need to implement one or a combination of the following measures: improve thermal insulation in the building envelope, upgrade radiators or individual units with larger ones, and perform hydronic balancing of the heating system to ensure optimal heat distribution among heating components.

Power system. The electrification of heating through heat pumps will influence electricity market dynamics such as market prices and generation mix by increasing the supply requirements and the system peak hourly demand. These effects can be mitigated by taking counter-measures in terms of smart operation of the heat pumps, inclusion of flexibility in the systems and demand response measures.

The analysis shows that for the whole EU, with 52.1 million ([6]) installed heat pumps by 2030, the heat pumps electricity demand will constitute 5% of total annual demand and reach as high as 11% during winter months. However, heat pumps will have a larger influence on the annual peak hourly demands, accounting for up to 9% if the heat pumps are assumed to operate with a 24 h constant temperature target. If a large share of heat pumps is set to turn off or to reduce temperature overnight, the peak demand risks being even higher in the

([4]) Considering the 2020 electricity mix

([5]) The specific low-temperature threshold varies based on the climatic region. According to a study, it is estimated that, for the case of Germany, the maximum flow temperature should not exceed 55 °C.

([6]) In addition to 30 million heat pumps replacing existing gas and oil boilers, we have also taken into account heat pumps installed in new residential buildings as well as those installed prior to today.

mornings. The high level contribution to peak demand can pose challenges to the grid by increasing generation supply requirements, and consequently pushing up prices and fossil fuel-based generation.

The analysis indicates that the additional strain on power grids due to the increased demand in terms of generation mix and power prices will be relatively moderate. However this does not take into account the additional grid investment costs which will be required with higher peak electricity demand and the risks that heat pumps could cause to local distributions networks. Moreover, this increased demand coincides with rising electricity usage in other sectors, such as transportation and industry, which could also add pressure to the system in unexpected ways. Finally, in countries where direct electric radiators are commonly used, if these are also replaced with heat pumps, the electricity needs wouldn't increase as much, or even be lowered.

Demand response flexibility strategies can alleviate a considerable portion of the stress which heat pump deployment will cause to the power grids. The electric shifting potential of heat pumps ranges between 0.18 and 10.68 kWh per heat pump unit and load-shift cycle, according to one study (Gunther, et al., 2020). The flexibility potential depends on the insulation of the building, the season (the potential is higher during winter when more electricity is used), and the flexibility strategy used. When extrapolated to a pool of one million heat pumps, the potential exists to shift a substantial amount of electricity demand, ranging from 4 to 14 GW per hour (Ibid). The EU has seen a positive trend in the regulation and implementation of demand response but there is still untapped potential to explore.

The impact of the deployment of heat pumps in combination with building envelope renovation were analysed in two separate scenarios and two heat pump operational modes. In Scenario 1, it is assumed that 30 million hydronic heat pumps replace existing gas and oil boilers, with 60% of the heat pump installation combined with building envelope renovation. In Scenario 2, only 30% of 30 million heat pump installations are combined with building envelope renovation. Another 30% of the buildings that would have opted for a deep energy renovation instead choose a hybrid solution, which involves an air-water heat pump combined with a condensing boiler. The result shows that Scenario 2 has a higher total electricity demand, which is driven by the level of energy renovation. This leads to higher annual electricity prices – 6% across EU countries – and higher fossil-fuel electricity generation – 6.5% in total.

The two scenarios were also tested under two different heat pump operational modes called Set A and Set B, which are shaped by different daytime temperature targets. In Set A, all the heat pumps switch on in the morning to reach the desired temperature during daytime hours. In Set B, the heat pumps maintain a 24-hour constant temperature, limiting any peak electricity consumption. The two modes were developed to understand the impact of two diverging heat pump dynamics and explore the range of impact on the electricity grid. Set B results in lower electricity prices overall – up to 5-10% for some EU countries – driven by a more distributed electricity load and reduced stress on the system during peak demand hours.

Challenges

The analysis looked more closely at several challenges that could influence the scale-up, including supply chain shortages, the lack of skilled installers, the high upfront costs for households, and the phase out of F-gases used as refrigerants in many heat pumps.

Skills and installers. The heat pump industry has grown to become one of the largest employers within the renewable energy sector in the EU, employing nearly 320 000 people. The European Heat Pump Association (EHPA) estimates that at least 500 000 skilled workers are needed in 2030 to meet an increase in demand (EHPA, 2023). A skilled installer should be able to verify the technical feasibility of a heat pump and define which type of heat pump and capacity are suitable for that specific house. Preferably, the installer also provides advice on additional renovation measures (i.e. change of windows, insulation of the basement, etc.) and explain how this can influence the heat pump's efficiency. The latter aspect is especially relevant with regard to replacing existing gas and oil boilers with heat pumps in older, inefficient houses. Furthermore, any intervention on the refrigerant-carrying circuit requires additional skills and knowledge. This includes mandatory training and certification requirements on fluorinated gases as per Regulation (EU) No 517/2014. Natural alternatives and very low Global Warming Potential (GWP) fluorinated gases pose additional challenges for installers and service technicians, primarily due to properties such as flammability, higher pressures and toxicity.

The accelerated deployment of heat pumps necessitates a fast-growing number of skilled professionals throughout the entire value chain. While there is demand for more installers with expertise in heat pumps, there is also a need for energy experts who can provide appropriate guidance to homeowners. They should advise on heat pump selection, sizing, integration into existing systems, and potential combination with other energy upgrades. It should be noted that the number of installers and their skill levels differ substantially between Member States.

Upfront costs. The high upfront cost is a genuine barrier. The initial investment required for an air-water heat pump typically exceeds EUR 10 000, considering the expenses associated with equipment and installations. In most cases, the upfront cost of an air-water heat pump can be more than double the cost of installing a new gas boiler. Additionally, many buildings will require modifications to their heating distribution system and potentially incur expenses for energy renovations. Air-air heat pumps have a significantly lower upfront cost compared to air-water heat pumps. However, they are typically used as a complementary heating solution rather than for heating an entire building. Nevertheless, they present an excellent opportunity to reduce the energy consumption of existing heating systems like gas boilers or direct electric radiators. By incorporating air-air heat pumps in conjunction with these systems, significant cost savings can be achieved. Financial support schemes ought to lower the barrier to invest in heat pumps and favour the most efficient systems based on building-specific considerations, taking into account cost, efficiency and climate impact.

Electricity/gas ratio. The price ratio between electricity and gas remains a challenge. The ratio plays a crucial role in determining the competitiveness of heat pump operating costs. When the price ratio exceeds the seasonal performance factor (SPF) of heat pumps, the fuel costs of heat pumps become higher than for gas boilers. Assuming a SPF of three, operating a heat pump remains cost-effective as long as the price of electricity does not exceed three times the gas or oil price. In 2021, 19 Member States had an electricity to gas ratio exceeding three, whereas only six Member States had a ratio of three during the first half of 2023. However, the more favourable ratios during 2023 are primarily due to the high gas prices, which also means the energy prices have increased overall, worsening the situation for the energy poor.

Achieving a favourable and stable electricity/gas ratio would allow heat pumps to maintain their efficiency advantage and ensure their economic viability compared to fossil-fuelled heating systems. The EU is currently planning to implement a new EU Emissions Trading System (ETS) that will encompass fuel combustion in buildings, along with the transport sector. This upcoming expansion of the ETS is expected to lead to a more favourable ratio for heat pumps. By including fuel combustion in buildings, the cost of fossil-based heating will increase as a result of emissions allowances.

Supply chain vulnerabilities. Heat pumps do not have any particular material vulnerabilities. Potential risks are related to general volatility in metals prices and the economy-wide shortage of semiconductors and permanent magnets. Semiconductors are used in different components of heat pumps such as controllers, compressors, pumps and fans. These chips, however, are not highly specialised or advanced, which means they can sometimes be sourced or repurposed from adjacent manufacturing sectors. There has been a strong EU policy response to try and address semiconductor (chip) dependency. With regard to permanent magnets, there are few short-term solutions to mitigate the potential disruption of imports from China. A discovery of rare earth metals used in such magnets was announced in Sweden in 2022 but will take time to become available on the market. In the longer term, recycling and substitution can be effective strategies. For example, to address the supply volatility of semiconductors, manufacturers could revert to simpler designs, such as alternating current fans.

Energy poverty. Heat pumps, combined with energy upgrades of building envelopes, can contribute to addressing energy poverty by increasing affordability through reduced utility bills. Reducing and decarbonising heat demand is the only viable long-term solution to combatting energy poverty, where energy cost rebates only offer a temporary relief. A heat pump is on average around three times more efficient than a gas boiler, reducing vulnerability to price fluctuations. However, when it comes to a household's ability to invest in a heat pump, key factors in decision-making are:

- the financial ability to purchase the new system (i.e. the upfront cost);
- the ability to participate given their tenure status: split incentives for building owners and tenants represent a major non-financial barrier to further adoption of heat pumps;
- the ability to accommodate a new heat pump system given the building's design and the planning regulations in the area;
- the affordability of electricity prices to operate it.

To address these issues, targeted financial support schemes and policy programmes are needed. For example, information campaigns explaining the cost benefits of heat pumps should be used to incentivise the 5.3 million financially stable but energy-poor households to switch to a more efficient energy system. Financial support ([7]) is needed for the 40 million privately owned and owner-occupied dwellings of financially vulnerable households. For the 60 million rented dwellings, regardless of financial status, innovative urban planning and housing policy intervention is required to tackle the split incentives problem.

Competitiveness of industry. The ambitious REPowerEU rollout target is not only a challenge but also an opportunity for the European heat pump industry. The industry is well established and innovative, leading in several heat pump segments. It is made up of many SMEs and a few large manufacturers, with none wholly dominant. There are around 170 heat pump factories in Europe, with the majority being assemblers only, rather than also component manufacturers. Many of the heat pumps sold and installed in Europe are also still manufactured in the EU, with only compressors largely imported from China. Thus, a large part of the value creation in the heat pump value chain stays within the EU. Demand growth has spurred EU manufacturing, which recorded the highest ever year-to-year increase of 30% in 2021 and reached EUR 3 billion in production value, based on Eurostat Prodcom data. Sweden has rectified its position as the biggest producer, ahead of France and Germany, although France has not disclosed its value for 2021. This indicates that the EU has a strong manufacturing base. However, it is yet to be seen whether European industry is able to scale up fast enough to meet the exploding demand. The EU has a strong foothold in innovation, but efforts are needed to maintain this edge, especially as value creation increasingly moves to digitalisation and system integration. Strong performance in innovation will help the EU industry to tap into the opportunities of the booming EU market, but it must better deploy economies of scale if it is to overcome cost-cutting competition from outside the EU. The industry needs long-term supportive regulations, including the removal of potential barriers in the Single Market to promote investment in EU manufacturing lines. It must avoid the fate of solar PV, which lost its industrial base in Europe.

Refrigerants and F-gases. Another challenge to the largescale deployment of heat pumps is related to refrigerants. Currently, most heat pumps use hydrofluorocarbons (HFC), a group of fluorinated gases (F-gases), as refrigerants, which are very potent greenhouse gases. There are natural alternatives to HFC, such as propane and CO_2, which receive increased attention due to the EU's F-Gas Regulation ([8]) and international treaties ([9]), which would reduce the warming effects of these refrigerants several hundred to thousands of times ([10]). An additional warming of 0.5 degrees can be avoided if currently agreed global F-gas measures are implemented. A recent publication has shown that in the sector of small split air conditioning which includes heat pumps, a transition from R410a (the conventional technology world-wide) to propane would avoid around 0.1 degrees of warming (Purohit et al., PNAS, 2022) ([11]). The current debate focuses on how fast the HFCs should be replaced.

The phase-out of F-gases could be challenging for industry in the short term. While such heat pumps and their components are available today, further upscaling and the creation of production capacities are needed. 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 (L. Lyons, et al. 2022). In addition, such action avoids the creation of large banks of equipment using refrigerants with high GWP, which saves significant amounts of direct emissions for several decades. Replacing these refrigerants quickly is therefore an opportunity for industry to move to truly green technologies. Administrative requirements for the use of natural refrigerants should be simplified and streamlined to support the industry in this transition.

The revision of the F-Gas Regulation tightens an existing quota system for HFCs to progressively limit the high-GWP refrigerants put on the EU market each year. This quota system has been designed to enable the rollout of heat pumps as envisaged under REPowerEU (30 million hydronic heat pumps by 2030). Nonetheless, some industry players would like to go slower and keep using conventional technologies. In this case, there is a risk of not sufficiently addressing the HFCs in heat pumps, locking in direct emissions for a considerable time, given that lifetimes are about 15 years and leakage tends to become more relevant in older equipment..

([7]) Albeit a too high financial support will induce an increase of the price.

([8]) F-Gas Regulation (EC) No. 517/2014 went into effect on January 1, 2015. A revision of this Regulation is currently being negotiated (April 2022).

([9]) The Paris Climate Agreement and the Kigali Amendment of the Montreal Protocol.

([10]) Currently used HFCs are R410a with a GWP of 2088 and R32 with a GWP of 675 (IPPC 4th Assessment Report). CO2 has a GWP of 1.

([11]) https://www.pnas.org/doi/full/10.1073/pnas.2206131119

Related JRC work

— Heat Pumps in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets (Lyons L. , et al., 2022)

— Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study (Carrara, et al., 2023)

— EU Challenges of reducing fossil fuel use in buildings - the role of building insulation and low-carbon heating system in 2030 and 2050 (Nijs, Tarvydas, & Toleikyte, 2021)

— European Climate Neutral Industry Competitiveness Scoreboard (CIndECS) Annual Report 2022 (Kuokkanen, et al., 2022)

— Energy poverty, transport poverty and living conditions - An analysis of EU data and socioeconomic indicators (Koukoufikis & Uihlein, 2022)

— The impact of REPowerEU on EU energy systems, JRC whole parts of policy documents (Koolen, De Felice, Kanellopoulos, 2022)

— Assessment of heating and cooling related chapters of the National Energy and Climate Plans (Toleikyte & Carlsson, 2021)

Quick guide

Chapter 2.1 explains how heat pumps work and the options for different building types. Chapter 2.2 presents the impact on gas exports and CO_2 emission reduction of replacing 30 million gas and oil boilers with heat pumps. Chapter 3 addresses the impact on the power system. Potential supply chain bottlenecks are then examined (Chapter 4.1), followed by skills deployment and training (Chapter 4.2), the role of refrigerants (Chapter 4.3). Issues related to vulnerable households are then illustrated (Chapter 5), and finally the competitive position of EU companies (Chapter 6).

Disclaimer: The conclusions and recommendations of this report do not imply any policy position of the European Commission.

1 Introduction

Heat pumps play a pivotal role in mitigating emissions within the heating and cooling sector, especially in buildings. With a higher efficiency and lower emissions than fossil fuel boilers, they are emerging as a crucial technology for the EU's decarbonisation transition. Moreover, the deployment of heat pumps can contribute to energy security while reducing the impact of sudden fluctuations in fossil fuel prices.

The heating of buildings is central to the EU's climate policies, as nearly 40% of final energy consumption and 36% of greenhouse gas emissions stem from buildings. Europe's buildings are old and inefficient, with over 40% of the buildings stock built before 1960 and 90% before 1990, before any stringent efficiency regulations were in place. Furthermore, a significant proportion of space heating still relies on fossil fuelled heat sources, mainly natural gas, but also oil and coal. This analysis looks at the opportunities and challenges associated with replacing oil and gas boilers with heat pumps, including the implications for the EU ([12]).

In 2021, heat pumps accounted for a market share of 21.5% of all domestic space heating systems. However, the market share varied greatly between Member States, with a 96% share in Finland and a more modest 16% in Germany and 13% in the Netherlands. (EHPA, 2022). According to preliminary data from the European Heat Pump Association (EHPA), the demand for heat pumps experienced a substantial increase in 2022. A total of 3 million heat pumps were added in the EU for space heating and domestic hot water, compared to 2.2 million units the previous year.

The EU has introduced several initiatives to further accelerate the deployment of heat pumps. The Fit-For-55 package ([13]) and REPowerEU Plan ([14]) call for a doubling of deployment rates and at least 30 million additional heat pumps by 2030, mainly hydronic. In parallel, the Renovation Wave ([15]) of the European Green Deal ([16]) aims to double the energy renovation rates by 2030 from around 1%, and promote deep energy renovations. The strategy sets out to renovate 35 million building units by 2030. Furthermore, the related Green Deal Industrial Plan ([17]) identifies heat pumps as one of the key technologies and the upcoming Net-zero Industry Act ([18]) supports local manufacturing of heat pumps in the EU. Most recently, the European Commission launched the EU Heat Pump Action Plan ([19]) to support the deployment of heat pumps based on four building blocks: (1) establish partnerships between key actors, (2) awareness raising and skills, (3) legislative measures, and (4) more accessible financial support.

This analysis examines the implications of accelerating the deployment of heat pumps, with the goal of assisting policymakers in identifying and addressing the opportunities and challenges. The report highlights key barriers to the ongoing heat pump wave, drawing attention to critical areas that might require extra consideration. The analysis covers:

- The performance of heat pumps in different EU building typologies and climates, and their associated energy savings and emission reductions (Chapter 2);
- The impact of heat pumps on the power system (Chapter 3);
- Potential bottlenecks (Chapter 4), including (1) supply chain vulnerabilities, (2) lack of skills and shortage of installers, and (3) refrigerants and the phase-out of F-gases;
- The impact of the heat pump transition on vulnerable households (Chapter 5); and
- The competitiveness of the EU heat pump industry (Chapter 6).

([12]) Coal boilers have been excluded as their market share is only sizeable in a couple of EU Member States, and the coal is mostly produced within the EU.

([13]) The Fit for 55 Package: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550

([14]) REPowerEU Plan: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en

([15]) Renovation Wave: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

([16]) European Green Deal: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en

([17]) The Green Deal Industrial Plan: https://ec.europa.eu/commission/presscorner/detail/en/ip_23_510

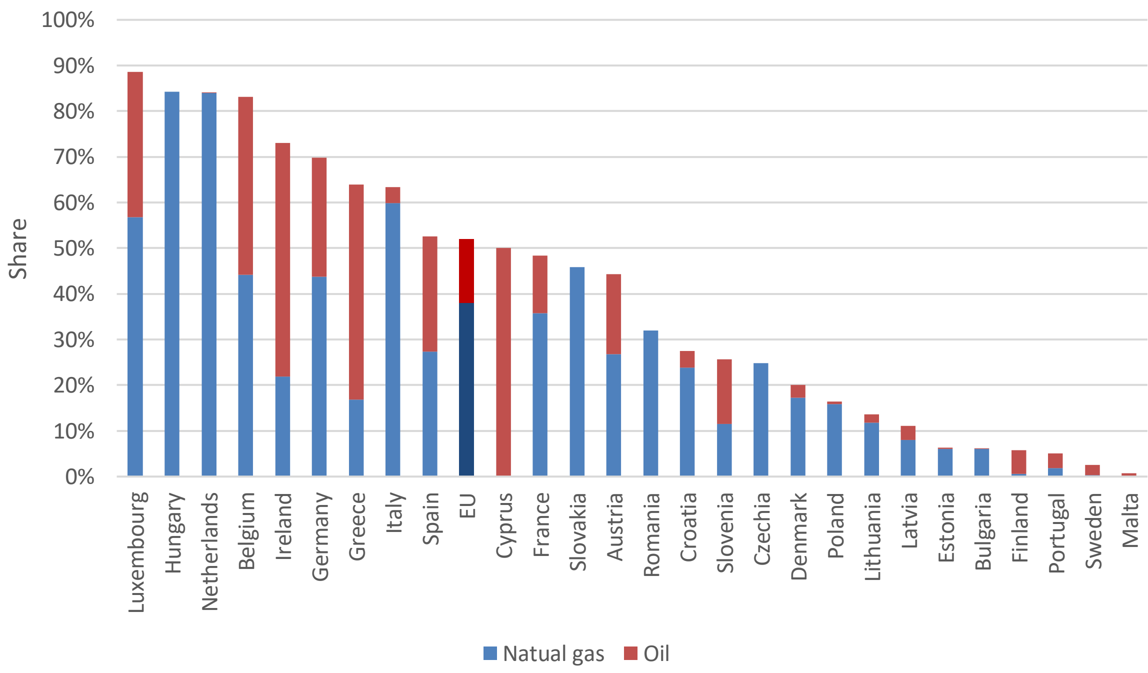
([18]) Net Zero Industry Act: https://single-market-economy.ec.europa.eu/publications/net-zero-industry-act_en

([19]) EU Heat Pump Action Plan: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13771-Heat-pumps-action-plan-to-accelerate-roll-out-across-the-EU_en

2 Decarbonising buildings with heat pumps

The total final energy consumption for residential space heating in the EU amounted to 1 784 TWh in 2020. Natural gas and oil accounted for more than half of the energy used for space heating, whereof natural gas itself represented 38%, while oil and petroleum accounted for the remaining 14%. The share of renewable energy sources, including heat pumps, is constantly growing and covered around 26.8% in 2020 (Eurostat, 2022). The energy mix varies across the EU, where natural gas supplied more than 50% of the energy needed for space heating in four Member States (Luxembourg, Hungary, The Netherlands, and Italy), but was close to insignificant in four other Member States (Malta, Sweden, Portugal, and Finland). Figure 2 illustrates the use of natural gas and oil for space heating in the residential sector across the EU.

Figure 1. Share of natural gas and oil in the total final energy consumption for space heating in households of EU Member States and the EU



Source: own visualisation based on (Eurostat 2022)

Russia's invasion of Ukraine prompted the EU to rethink its gas dependency, which had increased over the last decade compared to other fossil fuels. The EU's natural gas consumption increased by almost 2% during 2009-2019, while use of oil and coal decreased by around 35% (Nijs, Tarvydas, & Toleikyte, 2021). Furthermore, between 2012 and 2020, the sale of gas boilers increased, and in 2020 alone, more than 4 million condensing gas boilers were sold (ehi , 2020). New gas boilers replaced old gas boilers, and also old oil and coal boilers, to a large extent. In Germany, around 275 000 buildings replaced their oil boilers with gas boilers during the last 10 years (BDEV, 2019) ([20]). This transition has had a positive climate impact, as natural gas is less carbon-intensive than oil and coal, but also further entrenched the dependency on imported natural gas. During the last year the trend has changed, following the REPowerEU Plan to phase out imports of Russian fossil fuels, and the high gas prices of 2022. Gas consumption dropped by 20.1% from August to November 2022, compared to the average consumption during those months from 2017 to 2021 (Eurostat, 2022a).

The number and share of heat pumps have increased over a long time, albeit from a low level. The EU added 3 million heat pumps in 2022, reaching a total stock of around 22 million units, of which approximately 90% are used for space heating (EHPA, 2023). The number of heat pumps grew on average by 11% annually from 2011 to 2020 but during 2022, sales boomed, with an increase of over 42% (EHPA, 2023). For example, in

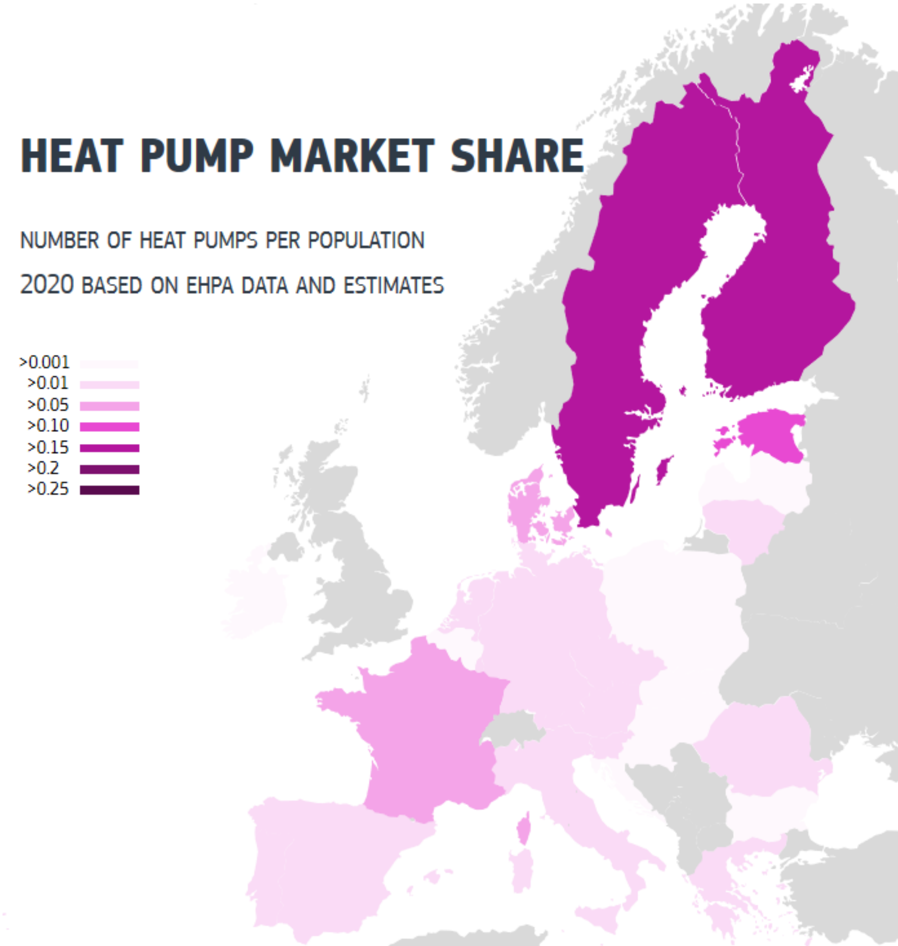
([20]) Another 17 000 from oil boilers to district heat

2022, over 600 000 heat pumps were sold in France, marking a 17% increase from the previous year, while 281 500 heat pumps were sold in Germany, a 59% increase on the previous year. (EHPA, 2023).

Heat pumps are more popular in new, residential, single-family- and terraced houses. The technology is a standard solution for new single-family houses in many Member States, for example Sweden and Finland with a share of 95% and 92% respectively (EHPA, 2022). In Germany, heat pump systems have also become the most popular heating system for new, single-family houses (Fraunhofer ISE, 2020). However, by 2021, the heat pump market share in multi-family houses was comparatively small, with less than 10% of all heat pumps sold having a capacity of more than 20 kW. Heat pumps are gaining importance in the sub-segment for renovation of one/two family houses and are perceived as the most promising in the long run (EHPA, 2022).

Figure 2 illustrates the existing stock of heat pumps in the EU in 2022. While growing quickly, heat pumps still represent a minor share of the existing stock in most countries. Around 22 million heat pumps have been installed compared to around 86 million gas and oil boilers. The map illustrates a rather modest market penetration of heat pumps in most countries, with the Nordics, Estonia and France being the exceptions. Installation numbers for 2021 and 2022 indicate a rapid increase of heat pump installations in most Member States.

Figure 2. Installed heat pump density in EU, in comparison with population size.



Source: own visualisation based on EHPA and Eurostat. Map design: Showeet

2.1 Heat pump options

Heat pumps can provide buildings with space heating and cooling, as well as domestic hot water. They work by using an ambient heat source (from air, water or ground) which is amplified by the heat pump and supplied through the heat distribution system. The most common heat pumps in buildings are vapour compression heat pumps driven by electricity ([21]). There are, however, different types of heat pumps on the market. They can be classified according to their ambient heat source (i.e. air, ground or water) ([22]) or by how they distribute heat (i.e. warm air (possibly via air ducts), hot water piped to radiators or underfloor heating (hydronic heat pumps)) ((Lyons L. , et al., 2022).

- *Air-water heat pumps* ([23]) and *ground-water heat pumps* ([24]) are hydronic systems which supply heat through a water-based distribution system (radiator, floor heating or fan coil). A hydronic heat pump can deliver the full heat demand and can therefore replace any existing heating system with a water-based distribution system ([25]). Air-water heat pumps made up 48% of all heat pumps for space heating sold during 2021, while ground source heat pumps (water-water or brine-water) accounted for 7% of sales (EHPA, 2022).
- High-temperature air-water heat pumps and ground-water heat pumps can reach flow temperatures of up to 80°C. These *high-temperature heat pumps* are equipped with suitable refrigerants such as propane which enables heat pumps to reach higher supply temperatures (Wüllhorst, Vering, Maier, & Müller, 2022). These heat pumps, however, typically have a lower efficiency compared to lower-temperature air-water or ground-water heat pumps. Moreover, the use of this technology has been restricted in building regulations in several Member States due to the flammability of propane. The regulatory obstacles are gradually being removed as the use of natural refrigerants has proven to be effective in a wide range of heat pumps. The use of high-temperature heat pumps in the residential sector is still rather limited.
- A*ir-air heat pumps* ([26]) draw heat from the ambient air and distribute it locally through an air heat exchanger. Typically, in central and northern Europe, a single air-air heat pump is rarely sufficient to meet the full heat demand of a standard building, and it is typically combined with another heat supply (Danish Energy Agency and Energinet, 2020). In contrast, in southern Europe, it is common for air-air heat pumps to provide all the heating or cooling required. Air-air heat pumps made up almost 44% of all heat pumps for space heating sold during 2021 (EHPA, 2022).

The efficiency of a heat pump is measured through its *coefficient of performance* (COP), a ratio between the delivered heat and the electricity used. Thus, a higher COP translates to greater efficiency in the heat pump's operation. The efficiency of heat pumps depends on operating conditions which include the temperature of the heat source (which is ambient temperature in the case of air-water heat pumps and the brine temperature in ground source heat pumps) and the temperature of the heat sink (flow temperature ([27])). Typically, the flow temperature is set by the heat pump controller or thermostat, and can be adjusted based on the heat load of the building ([28]).

While the COP indicates the performance of a heat pump for a specific time and conditions, the seasonal performance factor (SCOP) indicates the performance over a longer time period. The SCOP is used in Regulation

([21]) Other technologies are absorption heat pumps using a variety of heat sources such as geothermal or waste heat or gas or oil-fired solutions. These solutions are less efficient than electricity driven heat pumps.

([22]) Air-source heat pumps are also known as aerothermal heat pumps; ground-source heat pumps are also known as geothermal heat pumps.

([23]) Air-water heat pumps draw heat from ambient air using an outdoor unit, which is boosted by the heat pump and supplied as heat through a water-based heat distribution system (radiator, floor heating) (Danish Energy Agency and Energinet, 2020).

([24]) Ground-water heat pumps (also called brine-to-water heat pumps) absorb heat from the ground which is then boosted by the heat pump. The heat is delivered to the indoor unit which in turn is connected to the water-based heating system (radiators, floor heating, etc.) in the house (Danish Energy Agency and Energinet, 2020).

([25]) Sometimes buildings need to improve their building energy performance or install other measures such as new piping or larger radiators. Next chapter looks closer at the building's suitability to replace existing heat supply technology with a heat pump.

([26]) Most air-air heat pumps have one outdoor unit and one indoor unit and are often referred to as "split units".

([27]) Flow temperature is the temperature that leaves the heat pump's compressor and enters the heating distribution system.

([28]) As most heat pumps are now with variable speed compressor/fans, heat load has an important impact on the performance. Moreover, for hydronic heat pumps, the seasonal coefficient of performance (SCOP) can be increased by incorporating weather compensation law (when outdoor air temperature decreases, water temperature increases).

813/2013 that sets minimum energy performance requirements for space heaters and combination heaters, including air-air, air-water and ground-water heat pumps. To compare, the following list shows the minimum SCOP required by the Regulation and the maximum SCOP of the heat pumps selected from the top ten ([29]) database, see Table 1.

Table 1. SCOP requirements of Regulation 813/2013 and SCOP taken from topten database.

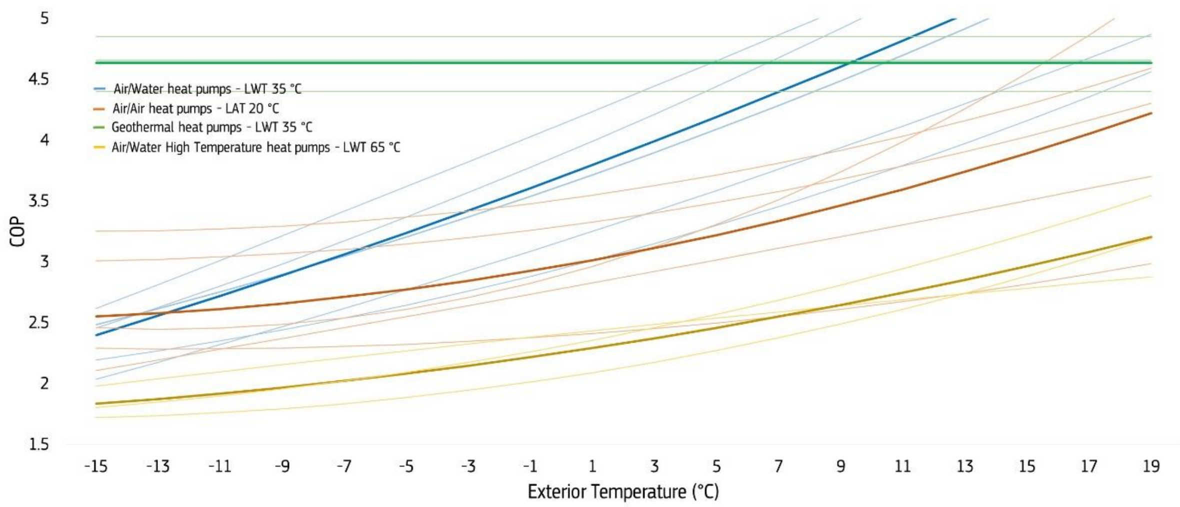
Type heat pump	Max. supply temp. [°C]	Minimum SCOP requirement	Highest SCOP (of the models in the topten database)
Air-air		3.8	6.2
Air-water	35	3.2	5.75
Air-water high temperature	55	2.8	4.75
Ground-water	35	3.2	6.0

Source: Regulation 813/2013 and topten database

Figure 3 illustrates the COP for various heat pump technologies at different exterior temperatures. Depending on the exterior temperature and the type of heat pump, the COP varies from almost 2 to more than 5 ([30]) ([31]).

As **Figure 3** indicates, air-water heat pumps and ground-water heat pumps are the most efficient technologies in these specific operating conditions. Ground-water heat pumps are less contingent on the external temperatures. The high-temperature heat pump has a significantly lower performance because it is operating at a higher temperature. The figure also illustrates the wide range of performance between different heat pump models using the same technology. It should be noted that the performance of the heat pump also depends on its quality and installation (right capacity, proper distribution etc.).

Figure 3. COP for four different types of heat pump as a function of the temperatures of heat source (exterior temperature) with constant heat sink temperature.



Source: own visualisation based on data provided by various manufacturers.

NL: LWT: leaving water temperature; LAT: leaving air temperature

Heat pumps are becoming more efficient over time. For example, one study finds that the efficiency of air-water heat pumps has increased by more than 70% since the early 1990s (IEA, 2022). Another study shows an increase in the efficiency of geothermal heat pumps by almost 70% from 1990 to 2000, and technological

([29]) https://www.topten.eu/private/products/heat_pumps

([30]) The COP values displayed in the figure were calculated using databooks provided by various manufacturers, and represent the nominal COP of the heat pump under specific conditions. It is important to note that these values cannot be directly compared to the SCOP written on the product label provided by the manufacturer.

([31]) The figure displays the COP of various selected brands, with the bold colored curves indicating their respective averages.

progress has continued since then (RHC-Platform, 2013). The SCOP is expected to continue to improve over the next decades as more investment is directed towards the technology.

Heat pumps can be combined with other heating technologies, and are then often referred to as hybrid heat pump systems ([32]). These hybrid systems consist of at least two appliances with different energy sources. The most common configuration is an air-water heat pump with a condensing gas boiler. The gas boiler component of the hybrid solution provides additional heating capacity when necessary, especially when outdoor temperatures are low. A hybrid heat pump can serve as an interim solution for buildings that will not undergo envelope renovations in the coming years. After the building renovation is complete, the hybrid system can be replaced by a full electric heat pump.

2.1.1 How suitable are heat pumps for different buildings?

Residential buildings with oil or gas boilers typically use hydronic systems using radiators for heat distribution. The operating temperatures of radiators can vary, based on factors such as building insulation, heat pump system, and radiator type. While newer and refurbished houses have efficient radiator systems operating at maximum temperatures of 45°C to 55°C, older and inefficient houses rely on higher temperatures due to radiator size and a higher heating load. In these houses, the temperature levels in the systems typically ranges from 65°C to 75°C ([33]) (IRENA, 2022) (Wüllhorst, Vering, Maier, & Müller, 2022) (Fraunhofer ISE, 2020).

Replacing boilers with heat pumps can present a challenge due to the high temperature requirements of many existing radiator systems. Heat pumps operate more efficiently with lower flow temperatures. The temperature of the heat source (exterior temperature in the case of air-water heat pumps), the supply temperature of the delivered heat and the heat load, influence the COP ([34]). Higher ambient heat source temperatures, and a lower supply temperature, result in increased efficiency (IRENA, 2022). To lower radiator temperatures, several measures can be implemented (Lämmle, et al. 2022):

— Enhance thermal insulation in the building envelope to reduce infiltration/ventilation heat losses (for instance replacement of old window frames with better airtight frames).

— Replace radiators with larger ones.

— Conduct hydronic balancing of the heating system to ensure proper distribution among heating components.

— Combine some or all of the above measures for greater impact.

To identify the optimal solution for reducing radiator temperatures in a building, an integrated system design approach is required that takes into account the individual building, hydronic system (radiators and pipes), and heat pump (Lämmle, et al. 2022).

A German study which monitored the performance of 56 heat pumps installed in existing single-family and terraced houses, concluded that heat pumps can work effectively in all types of building. The study also concluded that they work more effectively in well insulated buildings (Fraunhofer ISE, 2020). Moreover, the dimensioning of radiators (e.g. width, height and type of panel radiator) and their commissioning influence the required heating supply temperature (Fraunhofer ISE, 2020) (ifeu, 2021). Finally, underfloor heating offers the advantage of allowing the lowest maximum flow temperatures (35-45°C), resulting in higher heat pump efficiency due to its very large heat transfer surface area compared to radiators or mixed transfer systems (radiators in combination with underfloor heating) (Miara, 2021).

([32]) Bivalent heat pump is another term referring to a hybrid system which is not one integrated system. For example, when adding an air-air heat pump to an existing heating system.

([33]) It is important to acknowledge that the type and size of radiator used are supplementary variables that must be considered. Additionally, the relationship between building age and maximum water temperature is not linear. For example, in Germany, it was common to install smaller radiators in the 1980s and 1990s, resulting in higher flow temperatures compared to earlier decades, despite a decrease in energy demand.

([34]) In addition to these parameters, the design (sizing of radiators) and mode of operation (weather compensation law) also influences the efficiency of the system.

Figure 4 illustrates the renovation journey of a typical building. It indicates that the application of a heat pump is less suitable (red area) in buildings with a maximum flow temperature above 55°C ([35]) ([36]). The choice of 55°C as the maximum flow temperature for heat pumps is based on efficiency considerations. Above this temperature, the efficiency of air heat pumps (SCOP) typically drops below 2.5, resulting in higher operating costs compared to conventional heating systems. While lower temperatures would be ideal for optimal efficiency, 55°C is a feasible temperature for many buildings, even with moderate upgrades. Setting the maximum flow temperature too low would require certain buildings to undergo major upgrades to the building fabric or radiator system. Therefore, the choice of 55°C as the maximum flow temperature for heat pumps was developed as a compromise between ambition and feasibility. It should be noted this specific temperature trade-off of 55°C applies to Germany and is likely to differ across the EU (ifeu, RAP 2023).

The example in **Figure 4** shows possible renovation stages to achieve a "low-temperature ready" building: after renovating the façade, and adjusting the hydronic facility ([37]), the flow temperature sinks to 53°C which means that the building is low-temperature ready, and a heat pump can work efficiently. Further adjustments of the building can help reduce the flow temperature, resulting in a higher SCOP for the heat pump (ifeu, 2021). The concept of 'low temperature' serves as an orientation and draws attention to the importance of lowering temperatures in buildings, in preparation for a change of the heating system from conventional boilers to heat pumps or low-temperature district heating systems.

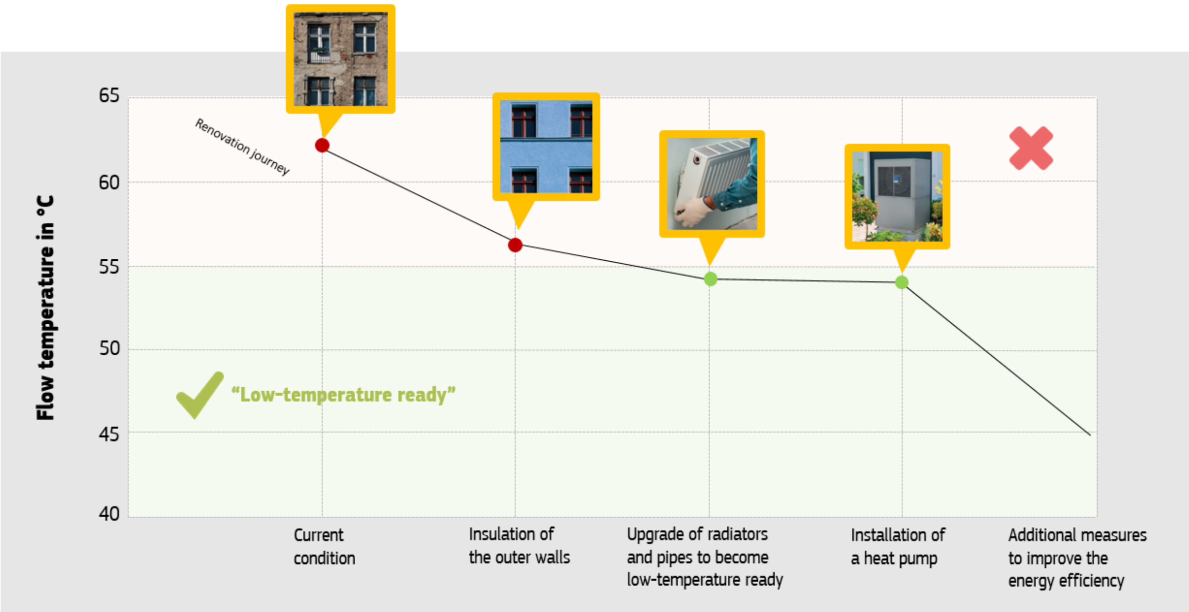
The inclusion of the Building Passport (BP) in the revision of the EPBD could be an important tool to assist building owners in determining which measures to implement. This instrument functions as an individual long-term renovation roadmap for every building, outlining future renovations and installations necessary for decarbonising the building. Additionally, it can provide links to the right energy experts and financial options (e.g. available subsidies) (BPIE, 2017). The main objective of the BP is to identify the optimal pathway towards achieving a zero-emission building. This involves determining the type and capacity of heat pumps, and exploring synergies with other planned measures, such as photovoltaics and batteries. The effectiveness of the instrument lies in its ability to alleviate two of the main barriers; the low awareness of the benefits of energy renovations and clean heating options, and insufficient knowledge regarding the implementation of measures and their order of priority (Volt, Fabbri, Zuhaib, & et al., 2020).

([35]) It should be noted that the SCOP value mentioned is not compliant with Regulation 813/2013, which sets the minimum SCOP for medium temperature air/water heat pumps (max water temperature 55°C) at 115%, which is roughly equivalent to an SCOP of 3. Moreover, according to the annex VII of the directive 2009/28/CE and the values proposed in 2013/114/UE, if the Seasonal Performance Factor of an electrically-driven heat pump is lower than 2.5, the ambient or geothermal energy captured from the heat source cannot be considered renewable. For that reason, solutions that require the heat pump to work at lower water flow temperatures by using terminal units as low temperature radiators or radiant floor, may be considered in order to benefit with the maximum renewable energy from the heat source.

([36]) This illustration shows a renovation journey for a single-family house from 1977. The current status of the building is as follows: roof and top floor ceiling were renovated in 2010; radiators and pipes are oversized with the flow temperature of 70°C. The first step towards "low-temperature ready" for this house would be to renovate the façade. Next, the hydronic adjustment would need to be done[36] and if necessary some radiators would need to be changed (in this example, the radiator in the bath was replaced). This renovation journey concept is not restricted to heat pumps only. It can be applied for other heating options as well. Source: (ifeu, 2021).

([37]) Upgrade of radiators and pipes

Figure 4. Examples of phases of building refurbishment towards climate-neutral building in the future: implementing low-temperature-ready measures and switching to renewable energy.



Source: adapted based on (ifeu 2021)

2.1.2 Heat pump performance in different buildings building types

This sub-chapter presents various performance indicators for different residential houses when switching from a gas boiler to a heat pump. We demonstrate the specific energy savings achieved (refer to the brief methodology description in the box below), discuss the Seasonal Coefficient of Performance (SCOP) for houses situated in different climates, illustrate the reduction in CO_2 emissions, explore the integration with photovoltaic (PV) systems, and finally evaluate the economic aspects of these investments.

Box 1. Methodology

To calculate the effects from switching from a gas or oil boiler to a heat pump, we selected a number of reference buildings. For each Member State, we used 21 different types of residential dwelling from the TABULA database ([38]), including single-family houses, multi-family houses, and apartment buildings, with varying construction years. We used available databases to define the technical parameters of the building envelope, climate data, and technical characteristics of heating systems. The EBEM model (see Annex 1. Methodology) was used to determine the specific energy consumption for heating with the current reference system (gas and oil boiler), as well as the energy consumption after switching to a heat pump, taking into consideration the building's heat load.

Typically, heat pumps provide both space heating and domestic hot water. However, this report solely focuses on space heating and does not consider the impact of domestic hot water usage on the operation of the heat pump.

Replacing a gas boiler with a heat pump will result in significant energy savings in typical single-family buildings in all Member States. **Figure 5** shows the energy use for gas (condensing boiler) and the energy use for electricity after switching to an air-water heat pump for selected reference houses across Europe. The specific energy need ([39]) of these houses does not exceed 150 kWh/m². These houses range in age from 13 to 40 years

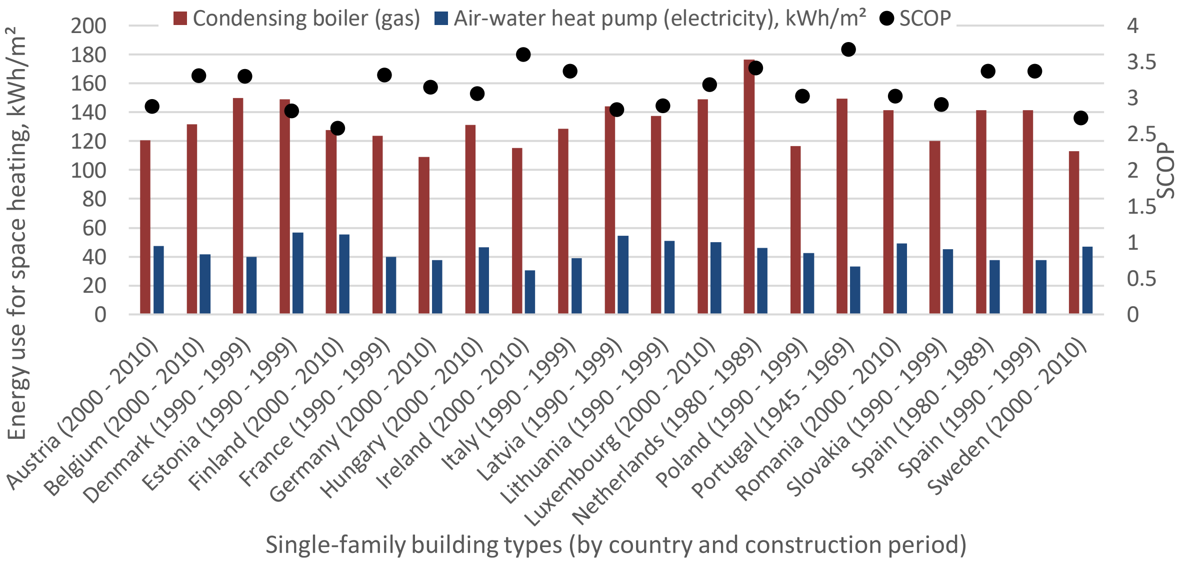
([38]) IEE projects TABULA and Episcope (IWU 2016)

([39]) Energy need for space heating is calculated based on the methodology from EN ISO 13790 and is defined as the heat to be delivered to, or extracted from, a conditioned space to maintain the intended temperature conditions during a given period of time. The factor representing behavioural aspects, the losses through the heating system and heating distribution system are not considered in this calculation step.

old, with the oldest one built prior to 1980. Our assessment indicates that the building envelopes of these selected houses likely do not require improvements for the heat pump to operate efficiently. However, in some cases, it may be necessary to upgrade radiators or individual units with larger units, and/or perform hydronic balancing of the heating system to ensure optimal heat distribution among heating components.

The final energy consumption of gas for space heating varies from 109 kWh/(m²*yr) to 177 kWh/(m²*yr) whereas the electricity consumption in the case of an air-water heat pump varies from 31 kWh/(m²*yr) to 57 kWh/(m²*yr) for similar buildings. The ambient energy extracted, for example, from the air by the heat pump, explains the difference between the two technologies. By replacing a gas boiler with an air-water heat pump in these houses, the final energy consumption could be lowered by as much as 78%. For example, a newer house in Austria (built between 2000 and 2010) would reduce its energy consumption from 120 kWh/m² of gas to 47 kWh/m² of electricity, while a house in Italy (built between 1990 and 1999) from 128 kWh/m² to 38 kWh/m². In this specific case, the potential savings for the house in Italy are higher, partly due to the higher ambient temperatures in Italy which allows the heat pump to operate more efficiently. The SCOP in Italy is higher compared to the SCOP achieved in Austria (3.4 and 2.9, respectively), indicating that heat pumps work more efficiently in higher temperate climates.

Figure 5. Final energy consumption for space heating by gas boiler and after switching to air-water heat pump in selected single-family houses

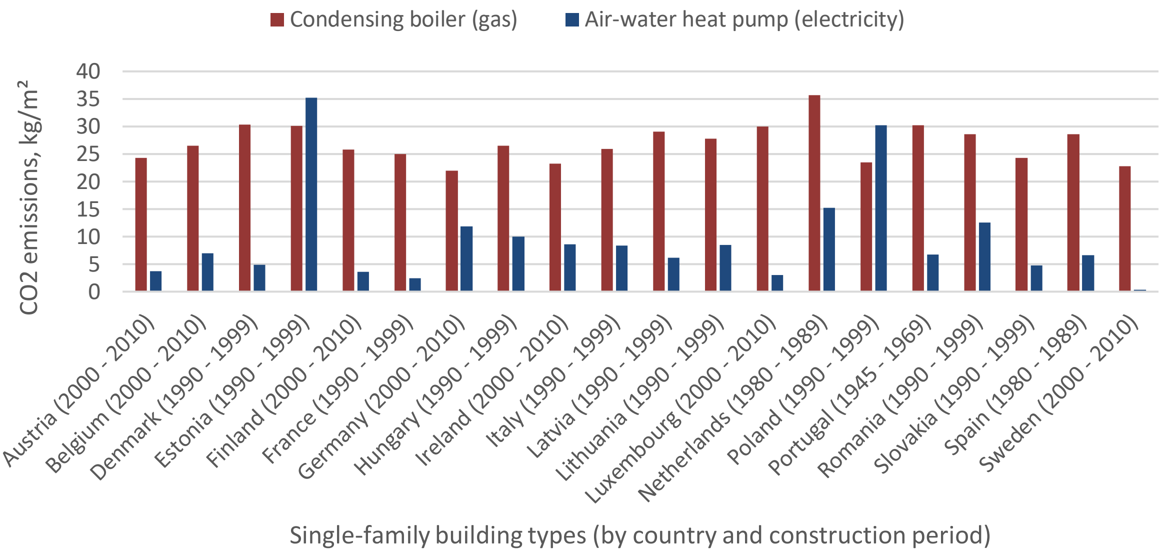


Source: own calculation

In the buildings analysed, a typical gas boiler emits between 22 kg/m² and 36 kg/m² CO_2 per heated floor area of a building into the atmosphere annually. Replacing such a gas boiler with an air-water heat pump could reduce CO_2 emissions by up to 96% (**Figure 6**), depending on the power system configuration ([40]). In most other countries, the switch from gas boiler to heat pump reduces CO_2 emissions by more than 50% (see Annex 3 for country-specific CO_2-emission factors). Due to the currently high CO_2-emission factor for electricity production in Poland and Estonia (710 and 621 g CO_2/kWh, respectively), houses switching from gas to heat pumps increase their CO_2 emissions in the short term. However, when more renewables and low-carbon sources are added to their electricity mixes, the installed heat pumps contribute to carbon savings. However, if the demand from heat pumps grows at a faster rate than the increase of renewables, it risks increasing the use of coal given the integrated European electricity market, meaning that the marginal additional demand of electricity in Austria might also lead to higher coal power generation in countries outside Austria.

([40]) We use the CO2-emission factors of electricity generation from the year 2020 based on (EEA 2022)

Figure 6. CO_2 emissions from heating by gas boiler and air-water heat pump in selected "low-temperature ready" single-family houses, considering CO2-emission factors of electricity generation from the year 2020



Source: own calculation

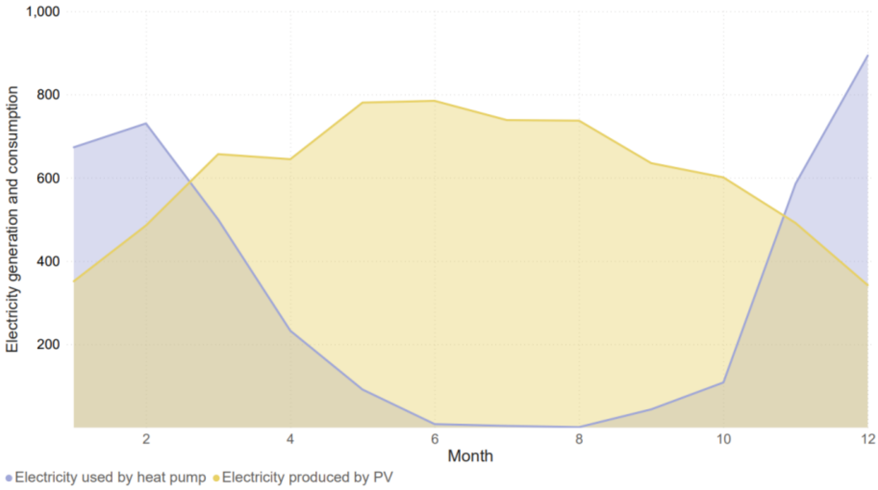
Heat pumps can be combined with solar photovoltaic (PV) to provide the heat pumps with direct renewable electricity and potentially reduce their impact on the power grid. Assuming that 20% of the surface of the roof is covered by solar PV ([41]), we calculate its monthly electricity generation and compare with the monthly electricity consumption of a heat pump used for space heating. **Figure *7*** shows the monthly electricity generation by PV and electricity consumption for space heating by heat pump, with the reference building located in the Netherlands and France (built between 1980 and 1999). The heat pump cannot use all the produced electricity directly due to the difference in demand and PV generation profiles. In most cases, the grid balances the onsite supply and demand, but a home battery could also be used for daily variations.

([41]) Assuming one module accounts for 1.7 m² with 0.32 kWp; each module is orientated to the south. We use PVGIS data of electricity generation with 1 kWp in specific geographic area.

Figure 7. PV generation and consumption for heat pump. For a reference single-family houses located in France (upper graph) and the Netherlands (lower graph), built between 1980 and 1989.

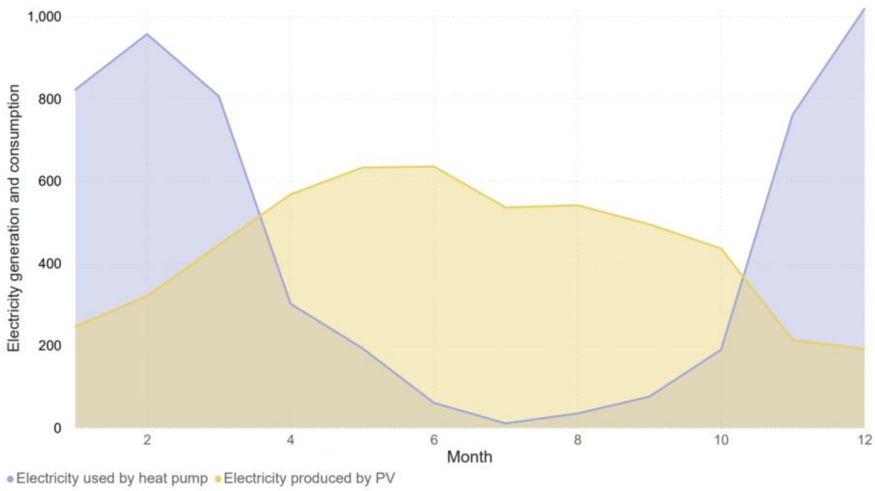
France

Monthly energy generation and consumption for a typical single-family house, kWh



The Netherlands

Monthly energy generation and consumption for a typical single-family house, kWh



*Source: own calculation based on data from IEE projects TABULA and Episcop*e (IWU, 2016), *PVGIS tool* (JRC, 2022).

Regarding the economic aspects of investing in electric heat pumps, the main parameters are equipment costs, installation costs, running costs for electricity and operation and maintenance (O&M) costs. Upfront costs (equipment) can vary from EUR 1 000 to EUR 10 000 depending on the type of heat pump and manufacturer. Installation costs depend on the heat pump type and on the country (i.e. cost of labour), and vary from EUR 200 to EUR 9 700 (see table below). The total cost of installing a heat pump is on average 2-3 times more expensive than installing a condensing boiler, with air-air heat pumps being the exception. Several countries offer subsidies for consumers who want to switch to heat pumps, e.g. VAT refunds (see examples from some countries in Annex 2 on national policies).

Table 2. Average investment costs of different heating technologies

	Air-air (5 kW)	Air-water (9 kW)	Geothermal (9 kW)	Condensing gas boiler (14 kW)
Equipment costs, EUR	1000 - 2200	5800 - 10000	5800 - 10000*	2280 - 3840

Installation costs, EUR	204-635	1680 - 5200	3050 - 9700	490 - 1510

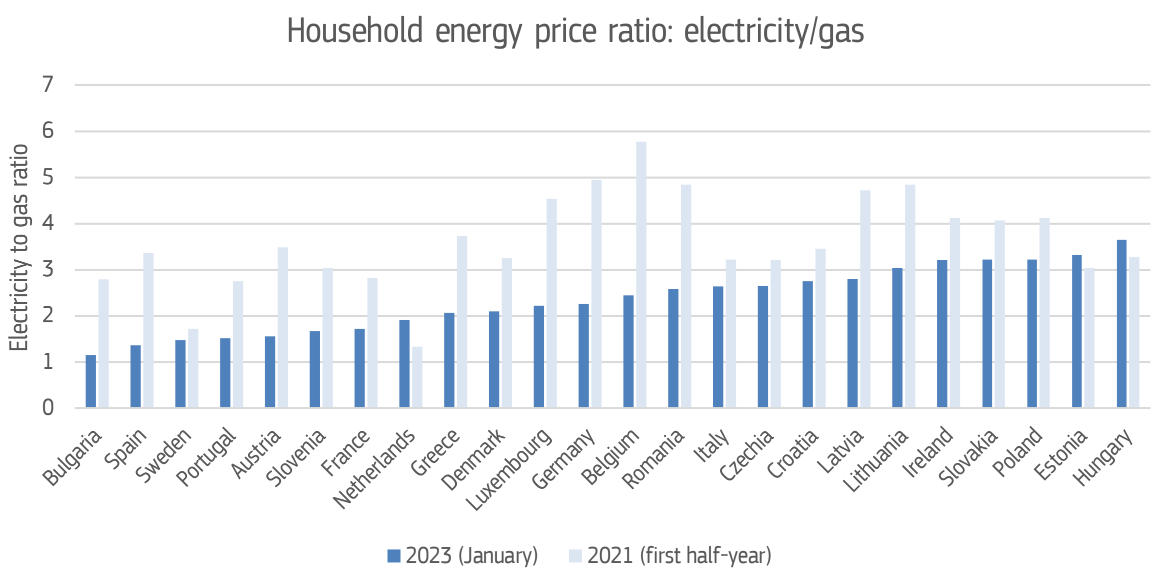
NL: 2022 equipment costs range is for different EU countries and for different brands currently on the market (we took prices from the following brands Bosch, Mitsubishi, Panasonic, Midea, Fujitsu, Daikin, Toshiba, Samsung, CTC, Nibe), installation costs range for different EU countries. Prices for single-family houses. Prices in 2022 gather from Sweden and Denmark and translated to Euro (SEK-EUR currency 19/10/2022). It should be noted the higher end marks the highest average cost in one of the Member States, not necessarily the highest cost on the market. For example, the cost for installing a geothermal heat pump varies significantly deepening on the location, and could easily cost up to 30 000-35 000 in some cases.

Source: Catalogues of different manufacturers, (Danish Energy Agency and Energinet, 2020), (Eurostat, 2022b), (Eurostat, 2022c), (Eurostat, 2022d)

Figure 9 compares the yearly running costs for three single-family houses which use a gas boiler and switch to an air-water heat pump. The heating costs for households using gas boilers are estimated to be 29 EUR/m², 31 EUR/m², and 31 EUR/m² annually in Austria, Italy, and the Netherlands, respectively, based on the energy prices projected for January 2023. However, if the same households used heat pumps instead, their bills would decrease by 40%, 20%, and 50%, respectively. The yearly energy cost saving for a 120 m² house in these conditions would amount to EUR 1 392, EUR 744 and EUR 1 860, respectively.

With regard to the financial viability of heat pumps across their lifetime (**Figure 10**), we see that instead the economic feasibility of switching from gas boiler to air-water heat pump depends greatly on the gas and electricity prices (**Figure 8**) ([42]). The relatively high gas prices of 2023 made heat pump investment more attractive, partly explaining the boom in demand. In Austria, for example, the electricity price was 3.5 times more expensive than gas in 2021 (first half-year) which made heat pump investment non-competitive. However, in January 2023, the price ratio was 1.6, which made the investment more cost-effective. In Italy, the ratio of electricity and gas prices was 3.2 in 2021 and it lessened to 2.6 in January 2023 due to high gas prices. In the Netherlands, the change from gas boiler to heat pump was cost-effective in 2021 and even more so in January 2023 prices. A typical Dutch household could save up to EUR 6 per heated m² per year from using a heat pump. Combined with PV panels, the running cost savings from using heat pumps are greater.

Figure 8. Household energy price ratio: electricity vs. gas in EU Member States in 2023 (January) and 2021 (first half-year)



NL: All energy prices provided include taxes and levies. The energy prices for 2023 (January) pertain to EU capitals, while the energy prices for 2021 (first half-year) represent average prices for Member states.

Source: (Eurostat, 2022e) (HEPI, 2023)

([42]) The financial viability of switching to a heat pump was evaluated by considering the total annualized costs over the expected lifetime. This includes both the initial investment (equipment and installation costs) and the savings in energy costs achieved by using a heat pump instead of a gas boiler. The analysis assumed a 16-year lifespan for air-water heat pumps and a discount rate of 4%.

Figure 9. Running costs for gas and electricity for single-family houses located in Austria, Italy and the Netherlands

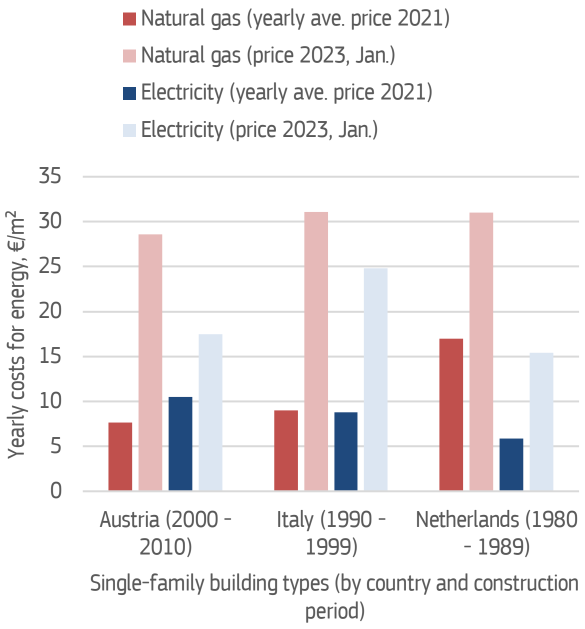
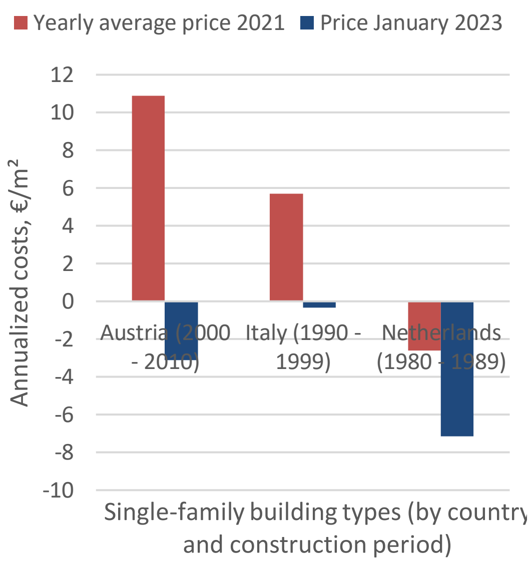


Figure 10. Total early average costs from switching from gas to heat pump (including savings on energy and investment cost)



NL: Positive values indicate additional costs, while negative values represent cost savings. Negative values indicate that investing in a heat pump is financially viable (Figure 10).

Source: own calculation based on data from IEE projects TABULA and Episcope (IWU, 2016), PVGIS tool (JRC, 2022), (Eurostat, 2022e) (HEPI, 2023) (Figure 10)

Figure 50 in the Annex shows the running costs for several houses across the EU, comparing the yearly costs with the gas and electricity prices in 2021 (yearly average) and 2023 (January). **Figure 51** in the Annex shows the financial attractiveness of heat pumps across their lifetime.

Compared to 2021, gas prices have largely increased in most of the countries. High gas prices increased households' heating bills substantially, rendering the investment in heat pump and building renovation a more attractive option. However, the high electricity prices are to some extent diluting this effect. In almost half of the assessed houses which are low-temperature ready, the change to a heat pump is nevertheless financially attractive. Our estimation shows that with current gas and electricity prices (2023 (January)), households can save up to 17 EUR/m² (in terms of running costs).

High upfront costs of buying and installing a heat pump can be a barrier for many consumers. Heat pumps cost two to three times more than gas boilers. Also, low gas prices compared to electricity prices can be an obstacle. This problem is also amplified in several countries where they impose higher levies and taxes on electricity compared to oil and gas (Rosenow, et al., 2022) (Lakeman, 2023). This is the case with the (pre-revision) EU Emissions Trading System which covers electricity consumption, and thus indirectly heat pumps, but not individual gas and oil boilers ([43]). At the same time, the high gas prices of 2022 have increased the future risk of depending on gas for heating, but is unknown to what extent households will take this into account if the prices stabilise at a lower level. Annex 2 provides an overview of economic policies from different countries showing various instruments such as direct financial support through subsidies for heat pumps.

([43]) This is being addressed in the latest revision of the EU Emission Trading System, which also will covered individual heating systems. https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en

2.2 30 million heat pumps by 2030

The REPowerEU Action Plan foresees the installation of 30 million heat pumps by 2030. As the aim is to make Europe independent of Russian fossil fuels before 2030, this study assumes that the 30 million heat pumps would replace existing gas and oil boilers in residential buildings. The REPowerEU plan aims to frontload the deployment of heat pumps compared to the Fit-for-55 targets. Thus, 10 million heat pumps will be added in the next five years, with a further 20 million new units to follow by 2030.

To analyse current and future energy trends, we apply a bottom-up approach based on a disaggregated building stock of the EU-27. We use the JRC EBEM building model (see methodology in annex). We identify the number of reference buildings per country based on the residential building type (single-family houses, multi-family houses, apartment buildings) and the year of construction. The IEE projects TABULA and Episcope (IWU 2016) are used for residential building specifications, whose database covers 17 of the EU's Member States. TABULA contains detailed technical information for typical residential buildings per country, such as heated area, U-values and area of building elements. The gap of the missing Member States was filled in using national sources or by transposing the data from a country with a similar building stock. 21 residential building typologies are modelled for each EU Member State. In addition to TABULA, we used building technical information from the H2020 project Hotmaps to calibrate the TABULA data and to ensure a higher correlation between the aggregated national bottom-up demand and the top-down demand provided by HOTMAPS, Building Stock Observatory ([44]) and Eurostat.

We analyse those building typologies that use gas and oil heating. Based on existing databases ([45]), we estimate that there are 68 million gas boilers and over 18 million oil boilers installed in residential dwellings ([46]). This makes up 57% of the total heating systems in residential dwellings (86 gas and oil boilers out of 152 million heating systems) and 53% of residential dwellings (142 million dwellings with gas and oil boilers out of 266 million dwellings). We made a further estimation of the allocation of these boilers among the dwellings built in different construction periods ([47]). Approximately 82% of all gas and oil boilers in residential dwellings are located in dwellings constructed prior to 1999 ([48]) (**Figure 11**).

([44]) The data in HOTMAPS and the EU Building Stock Observatory overlap to a large extent but HOTMAPS currently comprises more granular data and more recent data.

([45]) We made the estimation using the following data sources: JRC report (Nijs, Tarvydas, & Toleikyte, 2021), IEE projects TABULA and Episcope (IWU 2016), H2020 project Hotmaps (Pezzutto, et al. 2019), (ehi 2020), Study for DG ENER Mapping H&C (Fleiter, Steinbach and Ragwitz 2016).

([46]) A dwelling is a residential building or part of a residential building, which is designed or adapted for use as a separate dwelling, with its own entrance from outside or from a common area, and which provides a set of rooms for the exclusive use of the occupants. A dwelling may include one or more units, but the unit(s) must be for the exclusive use of one household only (TABULA project 2012)

([47]) We made the estimation using H2020 project Hotmaps (Pezzutto, et al. 2019), Study for DG ENER Mapping H&C (Fleiter, Steinbach and Ragwitz 2016), EU Building Stock Observatory (European Commission, 2023), JRC report (Nijs, Tarvydas, & Toleikyte, 2021)

([48]) It should be noted that the number of gas and oil boilers in not the same as the number of dwellings.

Figure 11. Number of installed gas and oil boilers in residential dwelling stock by construction period

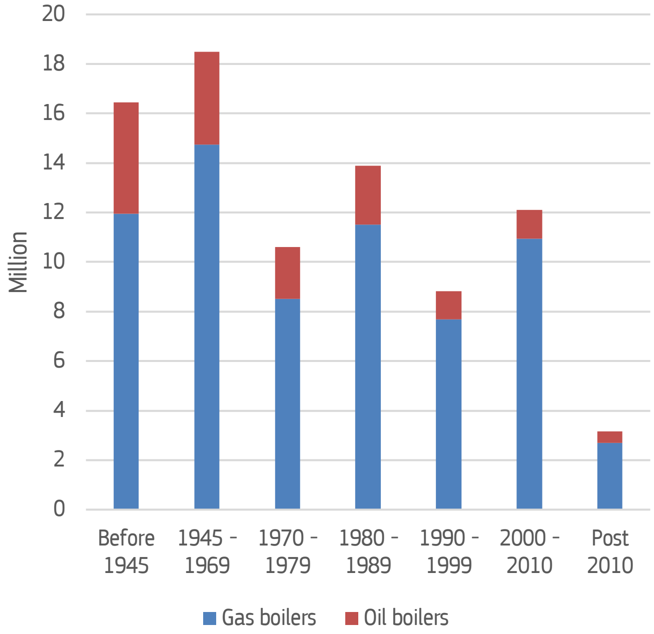
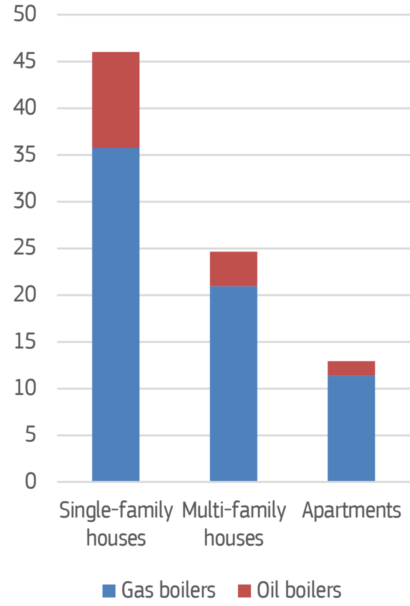


Figure 12. Number of installed gas and oil boilers in residential dwelling stock by type of buildings



Source: Estimation based on data from the EU Buildings Stock Observatory (European Commission, 2023), Study for DG ENER Mapping H&C (Fleiter, Steinbach and Ragwitz 2016), and H2020 project Hotmaps (Pezzutto, et al. 2019)

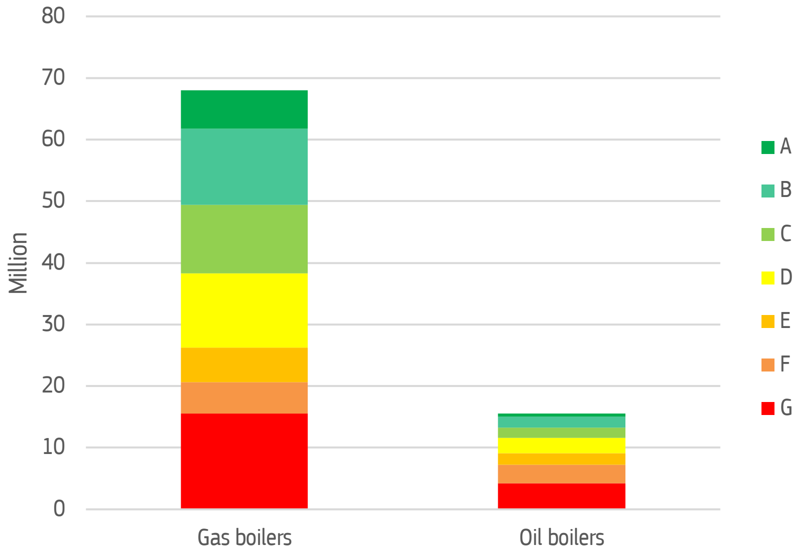
According to our estimation, the number of gas and oil boilers is quite evenly spread across buildings with different energy performance levels. For the reference dwellings, we calculated the energy performance of dwellings as the specific energy need (49) for space heating. We use the rating from A to G and distribute the gas and oil boilers in residential dwellings by a generic the energy performance thresholds (**Figure 13**), mirroring the Energy Performance Certificate approach. 41% of gas boilers are located in the best performing dwellings, with an Energy Performance Class of A, B, or C (50). Almost 35% of the gas boilers are located in dwellings with the Energy Performance Class of D, E, F, whereas 24% are located in the worst-performing dwellings (i.e., energy performance threshold G). There is a similar allocation of oil boilers, but these are less common in the highest-performing energy classes (51).

(49) Energy need for space heating is calculated based on the methodology from EN ISO 13790 and is defined as the heat to be delivered to, or extracted from, a conditioned space to maintain the intended temperature conditions during a given period of time. The factor representing behavioural aspects, the losses through the heating system and heating distribution system are not considered in this calculation step.

(50) Buildings constructed after 2010 are not included. We made the estimation using the following data sources: IEE projects TABULA and Episcope (IWU, 2016), H2020 project Hotmaps (Pezzutto, et al. 2019), (ehi , 2020), Study for DG ENER Mapping H&C (Fleiter, Steinbach and Ragwitz 2016).

(51) Data from BPIE, assessing the actual distribution of EPCs across the EU for all residential buildings, shows that almost 30% of dwellings have an energy performance class of A, B, or C, while around 50% of all dwellings with an EPC have a rating lower than D. The differences between this and our allocation can be explained by that gas and oil buildings are not representative to the all buildings (e.g. more single family houses which on average have a higher rating in many MS), the analyses databases by BPIE are not representative to all of EU (progressive countries generally have more developed EPC registries) or is our thresholds a bit too generous. BPIE (2017) 97% of buildings in the EU in need of an upgrade https://www.bpie.eu/publication/97-of-buildings-in-the-eu-need-to-be-upgraded/

Figure 13. Number of gas and oil boilers in residential dwellings with energy performance threshold from A to G, total EU27 residential building stock.



Rating	kWh/(m²*yr) threshold
A	**<50**
B	**<100**
C	**<150**
D	**<200**
E	**<250**
F	**<300**
G	**>300**

Source: own estimation based on IWU 2016, H2020 Hotmaps 2019, ehi 2019, Mapping H&C 2016

Projections to 2030 and scenario framework

This study assumes that the 30 million heat pumps would replace existing individual gas and oil boilers in residential houses by 2030. The quantity of gas and oil boilers in residential dwellings varies significantly among the Member States, resulting in a corresponding discrepancy in the proportion of installed heat pumps in existing dwellings for each country. Notably, Italy and Germany possess the largest number of gas boilers in dwellings, followed by France, Spain, and the Netherlands (refer to **Figure 14Error! Reference source not found.**). These countries alone account for nearly 75% of the total 68 million gas boilers. Regarding oil boilers in dwellings, Germany, Romania, and France have the highest numbers. To achieve the replacement of 30 million fossil-based boilers with heat pumps by 2030, the yearly average boiler replacement rate should be 5% ([52]).

In addition to 30 million heat pumps replacing existing gas and oil boilers, we assume that 10 million heat pumps are installed in the new constructions. The following assumptions are made to estimate the total number of heat pumps in the residential building stock:

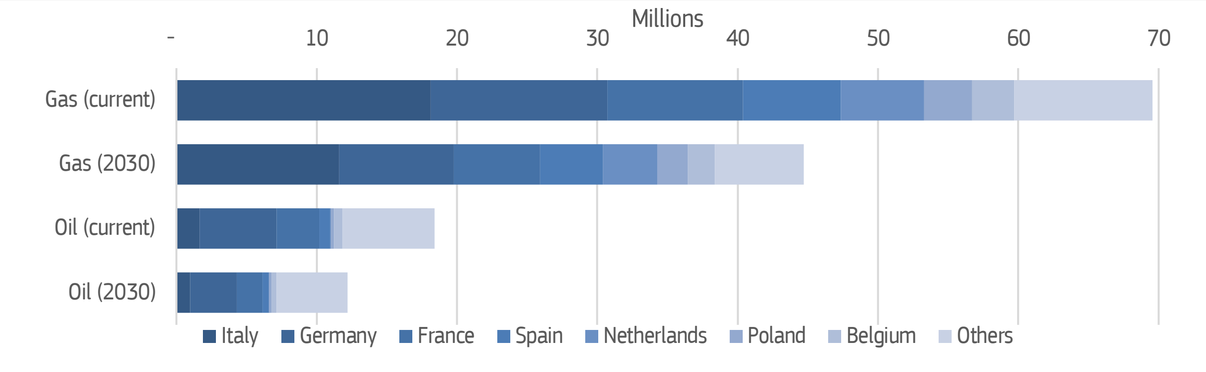
- Heat pumps in new dwellings: we assume that 70% of all new single-family dwellings and 10% of multi-family dwellings will install a heat pump system ([53]) ([54]). Electricity use from these heat pumps is relevant for the calculation of the total electricity use in the next chapter on "impact on power system". These heat pumps are added in addition to 30 million heat pumps which replace existing gas and oil boilers, and is assumed to be around 10 million.
- For the calculation of the total electricity use by heat pumps, we also account the historical data of heat pumps in dwellings (heat pumps installed prior today). We assume that these heat pumps were primarily installed in newer single-family dwellings.

([52]) We identified 567 building categories across Europe. Using information from TABULA, Hotmaps project and national statistics, we assessed number of dwellings with gas and oil boilers per category. We applied 5% of annual gas and 5.5% of annual oil boiler exchange rate to each building categories across Europe. We have also applied the building demolition rates as follows: a 0.2% annual demolition rate for buildings constructed before 1975 and a 0.1% annual demolition rate for buildings constructed between 1975 and 1990. These rates are based on the Hotmaps methodology (H2020 project Hotmaps).

([53]) Main source is the EHPA study and interviews with experts. We assume that these heat pumps have been installed in new single-family houses built after 2010

([54]) We assume that yearly construction rate is 1.1% (this was applied to residential dwelling stock in 2020).

Figure 14. Number of gas and oil boilers in residential dwellings currently and in 2030 after replacing 30 million boilers in the EU countries (countries ranked by the highest number of gas boilers)



NL: The analysis for 2030 focuses solely on the existing gas and oil boilers that remain in operation, excluding any new gas and oil boilers installed after 2022.

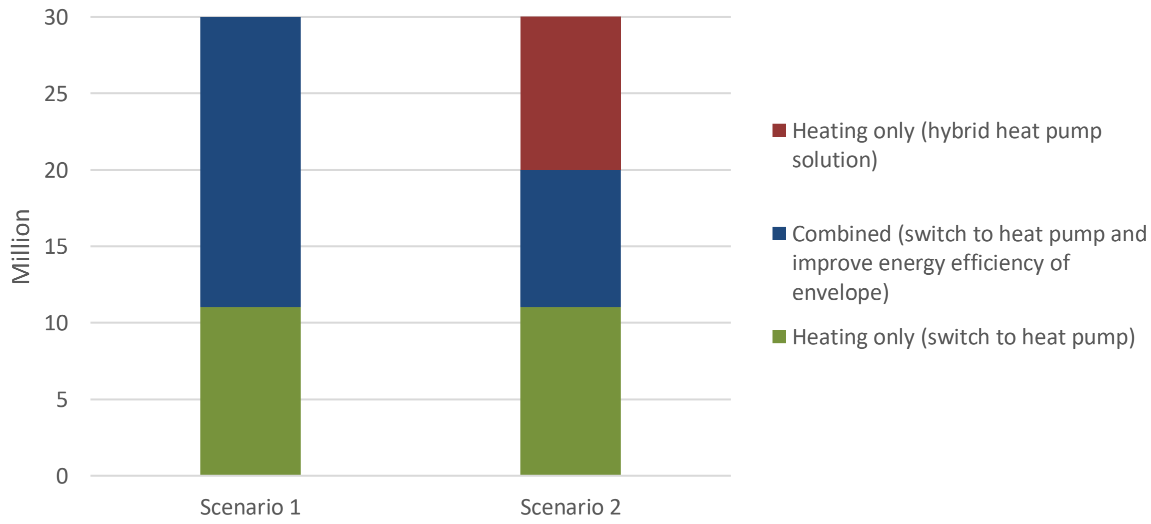
Source: own estimation based on IWU 2016, H2020 Hotmaps 2019, ehi 2019, Mapping H&C 2016

Scenario framework:

Two scenarios have been developed comprising the installation of an equal number of heat pumps, totalling 52.4 million by 2030. Out of these, 30 million heat pumps are replacements for existing gas and oil boilers, while the remaining are installed in newly constructed buildings.

In Scenario 1, approximately 40% of the installations involve a switch to a heat pump without any improvement in envelope efficiency, while more than 60% of the heat pump installations, including those replacing gas and oil boilers, are accompanied by building envelope renovation ([55]). However, Scenario 2 has fewer heat pump installations combined with building envelope renovation. In Scenario 2, 30% of heat pump installations are combined with building envelope renovation. Moreover, in Scenario 2, poorly performing buildings choose a hybrid solution that combines a heat pump with a gas boiler. It is worth noting that out of the 30 million heat pumps, 10 million are hybrid heat pumps (refer **Figure 15**).

Figure 15. Cumulated number of heat pumps in dwellings by 2030 which replace existing gas and oil boilers (installed prior 2020) in EU 27 in two scenarios

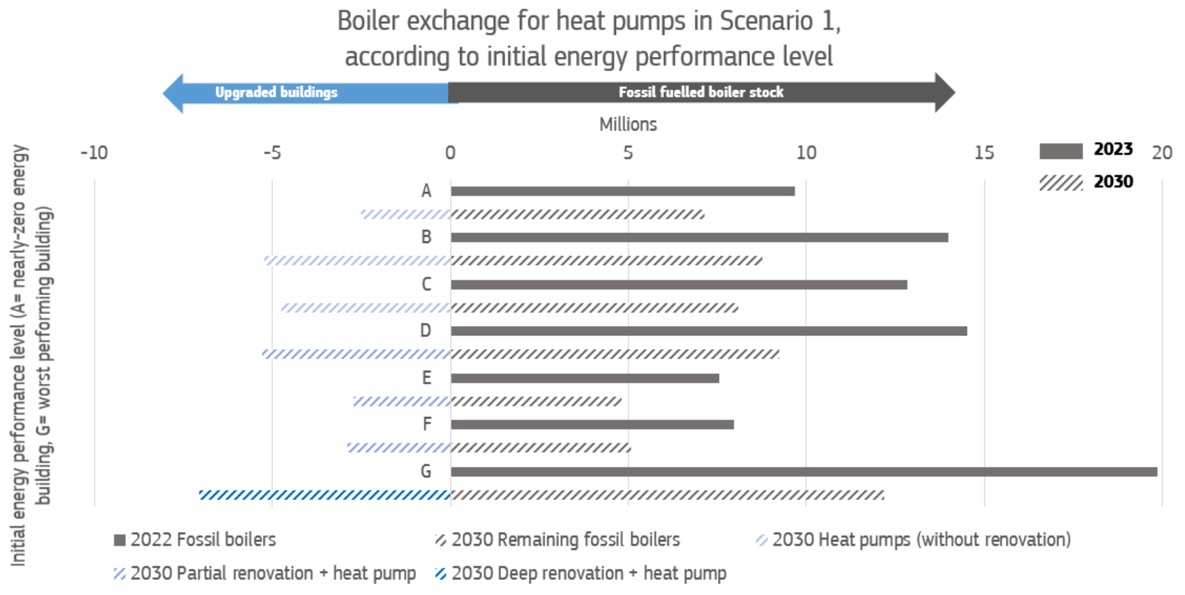


Source: own estimation

([55]) We made a simplified assumption that a heat pump can operate efficiently in buildings with a maximum energy need of 150 kWh/m². Our calculations indicate that among the 30 million cases considered, 40% have an energy requirement for space heating of 150 kWh/m² and below.

In Scenario 1 (refer to **Figure 16**), more than 9 million gas and oil boilers would be replaced with heat pumps in buildings undergoing partial renovations, which have been assigned an energy performance certificate (EPC) rating of D, E, or F. Additionally, around 11 million gas and oil boilers in the least-performing buildings, rated with an energy performance certificate (EPC) of G, would require a deep renovation before being replaced with heat pumps. Furthermore, we estimate that approximately 11 million gas and oil boilers could be replaced by heat pumps without any renovation since they are located in dwellings with an Energy Performance Class of A, B, or C. ([56]).

Figure 16. Number of gas and oil boilers in residential dwellings by building performance threshold currently and in 2030 as well as number of dwellings with heat pumps and partial and deep renovation in Scenario 1.



Source: own estimation.

2.2.1 Forecast/result

According to Eurostat's data from 2022, the total final energy consumption for space heating in residential dwellings across the European Union (EU) amounted to 1 784 TWh. Gas was responsible for 38% of this energy consumption, while oil accounted for an additional 14%.

According to our calculations, replacing 30 million existing gas and oil boilers with heat pumps and implementing partial building envelope renovations by 2030 would result in a 36% reduction in the total final energy consumption of gas and oil in those buildings. This reduction corresponds to 348 TWh of energy saved for residential space heating (results for) Scenario 1) ([57]).

In terms of gas consumption alone, the EU's residential buildings could save 255 TWh of gas, which is approximately 10 billion cubic meters (bcm) ([58]). This reduction is equivalent to around 7% of the gas imported from Russia in 2021 ([59]).

([56]) We define buildings that are currently using gas and oil boilers as "low-temperature ready" if their annual heating demand is less than 150 kWh/(m²*year). Our assumption is that these buildings can be fitted with a heat pump without the need for significant renovations to the building envelope, although there may be cases where radiators and pipes require replacement. This is a simplified assumption, and it should be noted that there is no direct correlation between a building's energy performance and the flow temperature in its radiators.

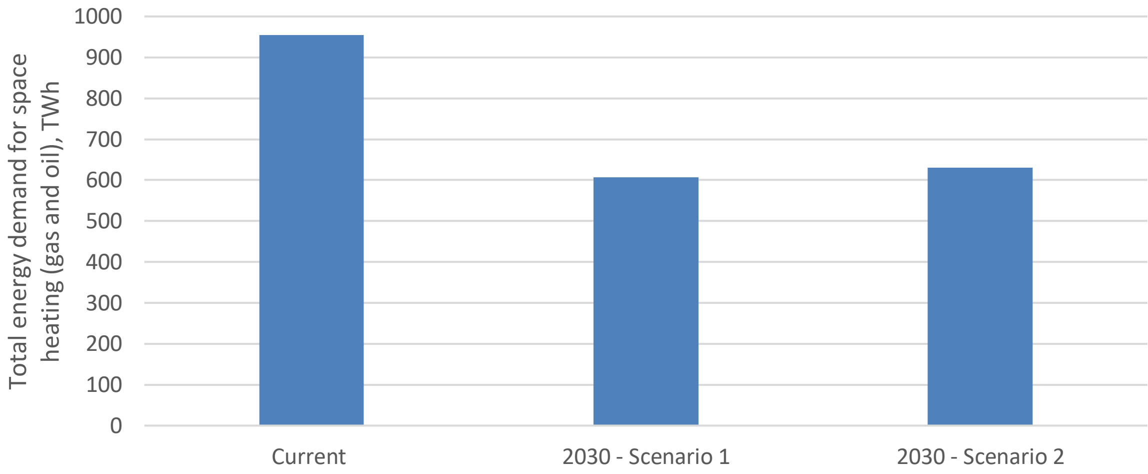
([57]) Our calculated current final energy consumption for space heating by gas and oil accounts for 955 TWh. Newly installed gas and oil boilers from 2022 to 2030 are not taken in this calculation.

([58]) 1 TWh = 0.038 trillion cubic meters (tcm) of natural gas

([59]) In 2021, European Union has imported around 140 billion cubic metres (bcm) for the year of gas by pipeline from Russia (https://iea.blob.core.windows.net/assets/1af70a5f-9059-47b4-a2dd-1b479918f3cb/A10-PointPlantoReducetheEuropeanUnionsRelianceonRussianNaturalGas.pdfhttps://iea.blob.core.windows.net/assets/1af70a5f-9059-47b4-a2dd-1b479918f3cb/A10-PointPlantoReducetheEuropeanUnionsRelianceonRussianNaturalGas.pdf)

Among EU countries, Germany stands to achieve the greatest reduction in gas and oil usage in absolute terms, with a potential saving of 125 TWh. It is followed by France with 50 TWh, Italy with 48 TWh, Spain with 22 TWh, and the Netherlands with 18 TWh (**Figure 18**).

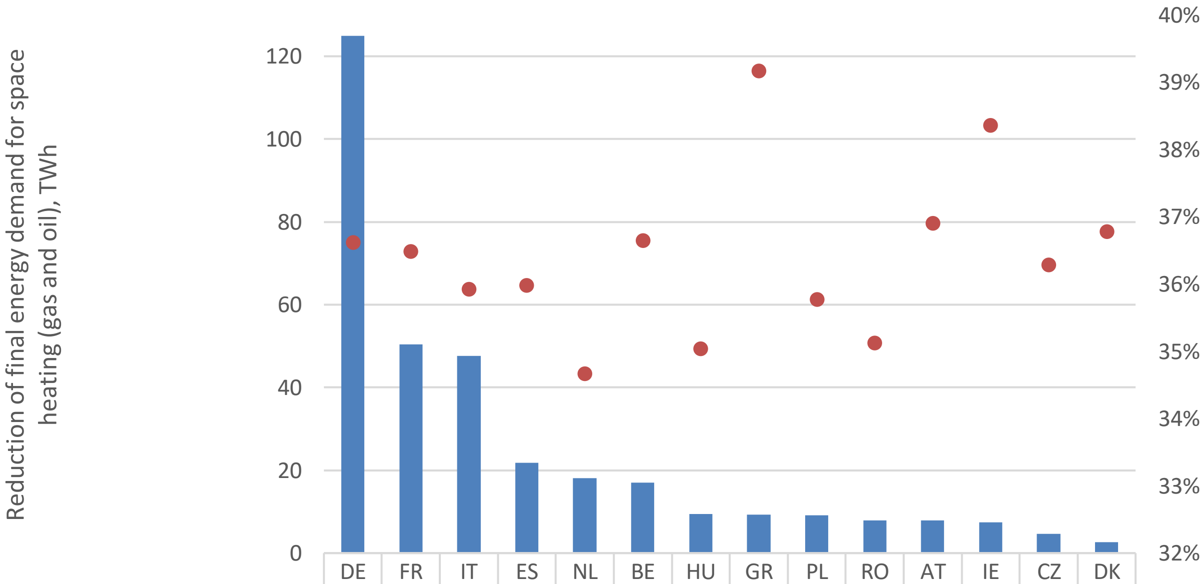
Figure 17. Total final energy demand for space heating by gas and oil boilers in EU residential buildings: 2020 and 2030.



NL: The analysis for 2030 focuses solely on the existing gas and oil boilers that remain in operation, excluding any new gas and oil boilers installed after 2022.

Source: own estimation.

Figure 18. Total reduction of energy use for space heating by gas and oil boilers in residential buildings in selected EU countries by 2030 (modelled values) (Scenario 1)



	DE	FR	IT	ES	NL	BE	HU	GR	PL	RO	AT	IE	CZ	DK
Oil and gas reduction, TWh	125	50	48	22	18	17	9	9	9	8	8	7	5	3
Reduction, %	37%	36%	36%	36%	35%	37%	35%	39%	36%	35%	37%	38%	36%	37%

NL: Selected countries with the highest saving potential ranked by savings.

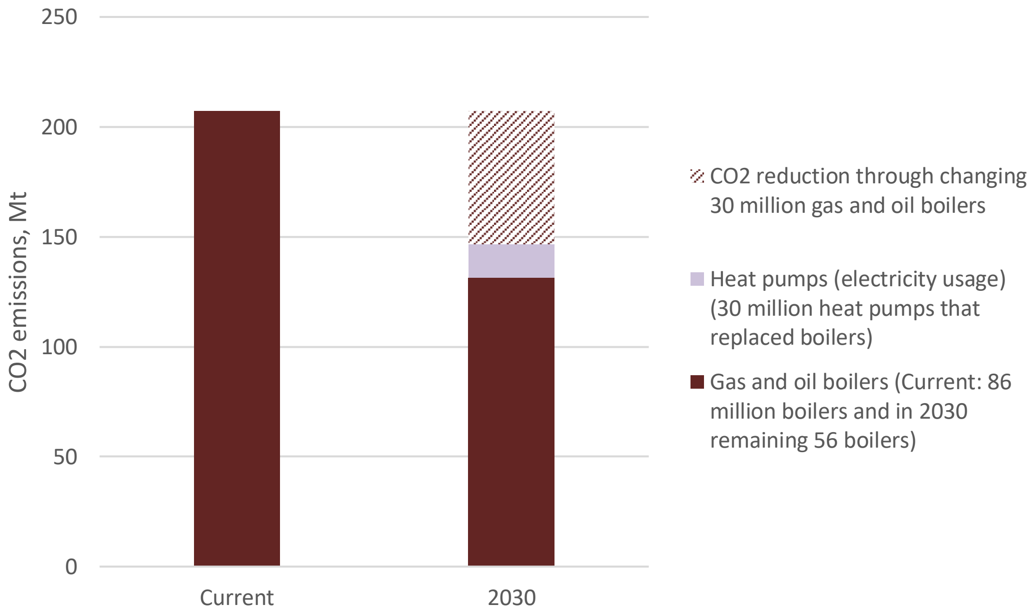
Source: own estimation

NL: The analysis for 2030 focuses solely on the existing gas and oil boilers that remain in operation, excluding any new gas and oil boilers installed after 2022.

According to the reported data from the EEA, the total CO_2 emissions resulting from the use of gas and oil boilers for residential space heating amounted to 211 Mt in 2020. These emissions represent nearly 50% of the total emissions generated from fossil fuel usage in buildings, which reached 449 Mt. ([60]).

Replacing 30 million oil and gas boilers, with 10 million dwellings switching solely to a heat pump and 20 million opting for both a heat pump and envelope renovation (in Scenario 1), would cause a reduction of 59 Mt CO_2 emissions. This reduction corresponds to 28% of the current total residential emissions generated by oil and gas, as depicted in **Figure 19**.

Figure 19. CO_2 emissions from heating residential households with gas and oil boilers in 2022 and 2023 in the EU (Scenario 1)



NL: The analysis for 2030 focuses solely on the existing gas and oil boilers that remain in operation, excluding any new gas and oil boilers installed after 2022.

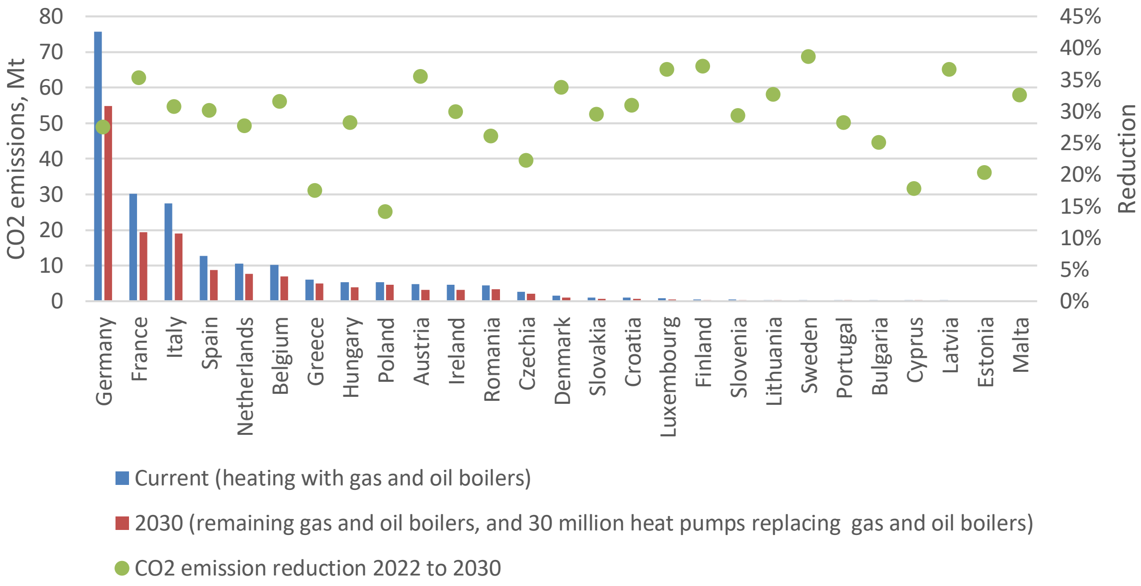
NL: considering CO2-emission factors of electricity generation from the year 2020.

Source: own estimation.

Looking at the country-specific reduction of CO_2 emissions, we see big differences between the EU Member States. The highest CO_2 emission reduction can be reached in Germany (21 Mt), followed by France (11 Mt), Italy (8 Mt), Spain (4 Mt), the Netherlands (3 Mt) and Belgium (3 Mt). The relative reduction is more comparable across the Member States, with the majority achieving a reduction ranging from 14% to 39%. The highest relative savings are observed in Sweden (39%), Finland, Latvia, Luxembourg (each with 37%), followed by Austria (36%), and France (35%), partly due to their low-carbon electricity mixes.

([60]) https://www.eea.europa.eu/ims/greenhouse-gas-emissions-from-energy

Figure 20. CO_2 emissions from heating residential households with gas and oil boilers in 2022 and 2023 in 27 EU countries (Scenario 1)



Source: own estimation.

3 Impact on power system

Total electricity demand from heat pumps is expected to increase significantly over the next decade. Heating demand follows climatic conditions and user behaviour patterns, contributing to the grid total electricity demand in intermittent ways across days and seasons. This chapter provides an analysis of the impact heat pumps will have on the EU electricity market dynamics, including system resiliency and adaptability.

For this analysis, the EU electricity market in the year 2030 – based on the REPowerEU scenario – is simulated using an energy economic equilibrium model based in Metis ([61]), a mathematical model simulating the operation of the European power system. The model simulates the hourly dispatch of generation technologies in the wholesale electricity market for the EU and neighbouring countries, considering the supply generation mix, demand profiles, underlying commodity prices and grid system constraints.

To calculate the total electricity demand generated by heat pumps installed in the EU's residential building sector by 2030, we rely on the data provided by the EBEM model. The number of heat pumps per country follows the same assumptions as outlined in chapter 2.3, titled "30 million heat pumps by 2030". The key assumption is that the 30 million heat pumps would replace existing individual gas and oil boilers in residential houses by 2030. Given the considerable variation in the number of gas and oil boilers across Member States' dwellings, the proportion of installed heat pumps in existing dwellings varies accordingly for each Member State. In addition to the 30 million heat pumps replacing existing gas and oil boilers, we consider the installation of 11 million heat pumps in newly constructed dwellings. Furthermore, we take into account the historical data of heat pumps in dwellings (those installed prior to today), which amounted to 11.4 million dwellings in 2022. The table below displays the total number of heat pumps expected to be installed in residential dwellings by 2030 for each country.

Table *3.* *Assumed total cumulative number of heat pumps installed in residential dwellings of EU Member States by 2030*

Country	**IT**	**DE**	**FR**	**ES**	**NL**	**PL**	**RO**	**SE**	**FI**	**BE**
[Mill]	10.34	9.79	8.15	5.32	2.80	1.71	1.63	1.46	1.41	1.37
Country	**GR**	**AT**	**PT**	**CZ**	**HU**	**DK**	**IE**	**BG**	**SK**	**HR**
[Mill]	1.29	1.04	0.97	0.89	0.88	0.70	0.47	0.45	0.33	0.26
Country	**EE**	**LT**	**SI**	**CY**	**LV**	**LU**	**MT**	**Total**		
[Mill]	0.23	0.21	0.12	0.11	0.10	0.09	0.03	**52.4**		

NL: Ranked by the highest number of heat pumps

Source: own estimation.

The same scenarios described in the previous chapter are being considered, namely Scenario 1 and Scenario 2. Both scenarios involve the installation of an equal number of heat pumps. In **Scenario 1**, more than 60% of the heat pump installations, which include those switching from gas and oil boilers, are combined with building envelope renovation. On the other hand, **Scenario 2** has fewer heat pump installations that are combined with building envelope renovation accounting for only 30% of the total. Additionally, in Scenario 2, the poorly performing buildings opt for a hybrid solution, which combines a heat pump with a gas boiler. Out of the 30 million heat pumps, 10 million are hybrid heat pumps (see **Figure 15**).

The model accounts for all grid level connected electricity demand stacking on top of the electricity load derived by residential heating. This was determined on an hourly basis by simulating the behaviour of electric heat pumps with respect to the air temperature, their operating characteristics and the heat consumption by the EBEM model (see Annex 1. Methodology).

For both Scenario 1 and Scenario 2, two different operational modes (Set A and B) were explored, shaping the hourly load profiles of the heat pumps. The two set were developed to explore two diverging setting and assess the impact of the resulting load profiles to the electricity system.

([61]) METIS is the European energy system model developed by Artelys since 2015 on behalf of the European Commission's DG ENER. For more information, see https://energy.ec.europa.eu/data-and-analysis/energy-modelling/metis_en.

The operational modes are based on different assumptions regarding the working hours of the system and the desired thermostat temperatures, as described below:

- In **Set A**, the thermostat is set to 20°C from 08:00 to 23:00, and it is set to 17°C from 00:00 to 08:00. This setting leads to a higher electricity load in the early hours of the morning when the system activates to bring the building at the desired temperature after the night period;
- In **Set B**, the thermostat is set to 20°C for the whole duration of the day which leads the heating system to operate continuously without switching on and off. This allows the system to maintain a more constant electricity profile and limit peak consumption hours.

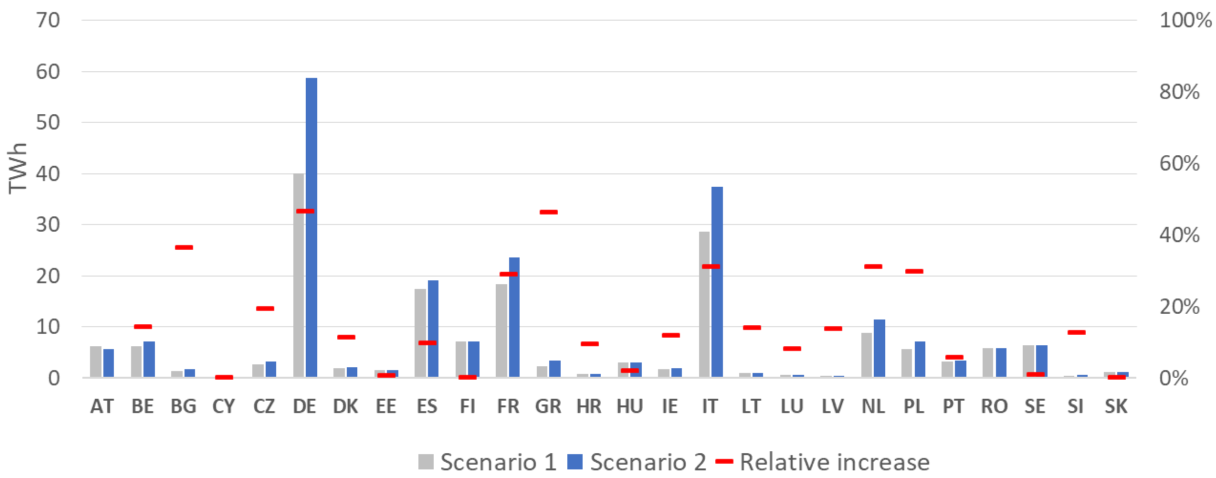
Even though Set A and B present different hourly operational profiles, at annual level the total electricity consumption is almost the same so Set A is taken as default when showing annual demand results.

3.1 Heating load demand

The residential heating electricity load is a direct function of the average building heating profile, differing by heat pump technology type, multiplied by the number of buildings. Scenario 2 has a higher electricity demand driven mainly by two factors, (1) the heat pump technology type (in addition to air-water heat pumps there are also hybrid heat pumps (air-water heat pumps combined with condensing gas boilers) and (2) the assumed level of building renovations.

In Scenario 1, more than 60% of the heat pump installations, which include those switching from gas and oil boilers, are combined with building envelope renovation, whereas in Scenario 2, only 30% of heat pump installations are combined with building envelope renovation. The remaining 30% opt for a hybrid heat pump instead of installing heat pump in combination to the renovation as in Scenario 1 (refer to Chapter 2.2 and Annex 1 for the methodology regarding the calculation of electricity consumption by hybrid heat pump). This leads to a higher electricity consumption in Scenario 2 compared to Scenario 1 (see **Figure 21**). Total EU-27 HP demand increases from 173 TWh total annual demand in Scenario 1 to 216 TWh, a 24% increase.

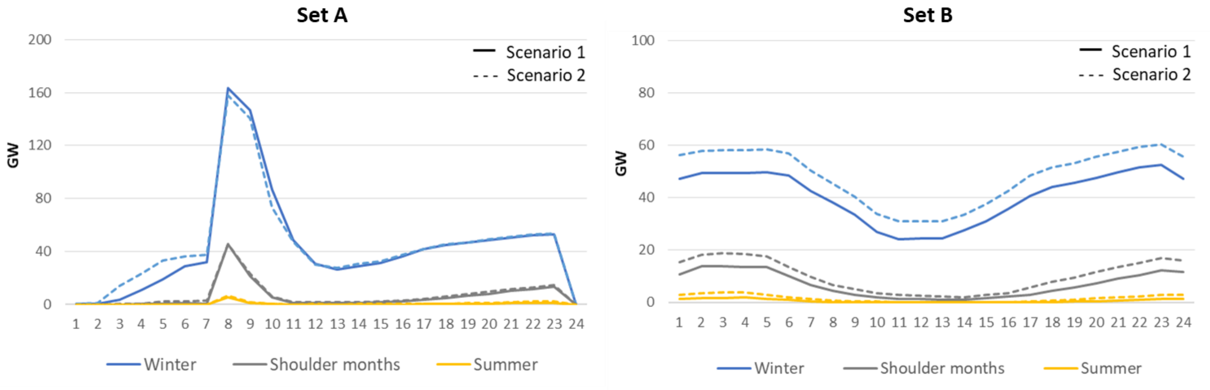
Figure 21. Scenario 1 and 2 heat pumps annual electricity demand per country and relative increase in Scenario 2 (Set A is used as default for annual data)



Source: own estimation.

The total EU electricity demand for residential heating is highly seasonal with heating load highest in winter, reducing to less than a third in spring and autumn and reaching close to zero in summertime (see **Figure 22**).

Figure 22. Average EU heat pumps seasonal hourly electricity demand in Scenario 1 and 2 (Winter: Nov-Mar, Shoulder months: Apr-May/Sep-Oct, Summer: June-Aug) for Set A and Set B



Source: own estimation.

The hourly electricity requirements depends on the operational mode of the heat pump systems which is regulated by the set thermostat temperature. The different temperature modes in Set A and B produce almost opposite shapes in the resulting hourly electricity load.

Set A is characterised by a high morning electricity peak produced by higher heating requirement to bring the building temperature back to the target, a lower more stable load during daytime to maintain the building temperature and a moderate rise in the evening to increase thermal comfort.

Set B heating requirements is inversely proportional to the heat coming from the external environment, with less electricity load during peak daytime hours and higher demand during nigh time when outside temperatures are lower.

Comparing the two result sets, it is clear how big of a role the operational dynamics of heating systems will play in both the shape and magnitude of European heat pumps electricity demand. This in turn will have a big impact in determining the contribution of heat pump to total electricity peak demand which is a fundamental factor when planning future generation capacity and grid requirements.

It should be noted that the two sets represent two extreme scenarios, where all heat pumps behave in one way or the other. The reality is, of course, not that simplified. The decision to lower the temperature of the heat pump during night depends on occupant's preferences, energy-saving goals, or the specific characteristics of the heat pump system and distribution system. Furthermore, heat pumps behave differently, where some controlled fully manually, while others semi-automatic or fully automatic. For example, some heat pumps are able to respond to price fluctuations on the electricity market, while others aren't. In other words, the two sets describe two extremes, in which the reality is somewhere in between.

3.2 Electricity market demand

Heat pumps have an impact on the electricity market dynamics by increasing the electricity demand in the grid and thus the supply requirements. Heat pumps demand contributes not only to increase the total volume of electricity demand but also the hourly peak demand, defined as the maximum instantaneous value drawing power from the grid. The peak value is particularly important as it is used for power system planning to make sure enough supply generation capacity is available at any time. The results of the analysis for Scenario 1 and a comparison between the heat pumps operational modes are reported in the following table. The results for Set A and B look very close when looking at total electricity demand while a strong difference is evident for the hourly peak values. While monthly demand volumes follow similar patterns and contributions, the EU system peak demand and heat pumps contribution in Set A is much higher driven by the heating profile of the heat pumps.

Table 4. Average monthly EU heat pumps (HP) total electricity and peak demand in absolute terms and relative share of total system electricity in Scenario 1 for Set A and B (Scenario 2 follows a similar trend but with higher contributions)

Scenario 1

HP Operational Mode Set A

Month	Total Demand: EU Grid (TWh)	Total Demand: HP (TWh)	Total Demand: HP Share	Hourly Peak Demand: EU Grid (GW)	Hourly Peak Demand: HP Contribution (GW)	Hourly Peak Demand: HP Contribution Share
1	346	32	9%	741	264	36%
2	318	34	11%	672	270	40%
3	343	24	7%	776	249	32%
4	309	8	3%	672	75	11%
5	290	3	1%	631	0	0%
6	273	1	0%	611	0	0%
7	274	0	0%	586	0	0%
8	273	0	0%	592	0	0%
9	272	1	0%	603	0	0%
10	278	6	2%	563	2	0%
11	323	26	8%	695	208	30%
12	353	39	11%	684	258	38%
Tot.	**3653**	**173**	**5%**	**Max. 776**	**270**	**40%**

HP Operational Mode Set B

Month	Total Demand: EU Grid (TWh)	Total Demand: HP (TWh)	Total Demand: HP Share	Hourly Peak Demand: EU Grid (GW)	Hourly Peak Demand: HP Contribution (GW)	Hourly Peak Demand: HP Contribution Share
1	344	31	9%	629	56	9%
2	317	32	10%	632	34	5%
3	343	23	7%	705	36	5%
4	311	9	3%	627	6	1%
5	292	3	1%	632	4	1%
6	274	1	0%	611	0	0%
7	274	0	0%	585	0	0%
8	273	0	0%	592	0	0%
9	272	1	1%	603	0	0%
10	279	6	2%	564	2	0%
11	323	26	8%	621	31	5%
12	350	36	10%	650	43	7%
Tot.	**3652**	**169**	**5%**	**Max. 705**	**56**	**9%**

Source: own estimation.

In terms of total volumes for both operational modes, heat pump contributes on average to 5% of EU annual electricity demand with a maximum monthly value of 11% during winter months. While not negligible these values should not constitute a major risk to the grid and will be easily met by rising renewable generation.

A different story emerges for the grid peak demand with heat pumps contributing a much higher share but only when operated as in Set A, characterized by a high morning consumption peak. When heat pumps are switched on in unison their combined electricity consumption reaches up to 40% of the grid monthly peak demand. While 40% is the highest contribution in February, heat pumps contribution to the annual peak demand is lower at 32%, when it coincides with the March value which is the maximum peak value for the simulated year. We can clearly see how the peak demand contribution in Set B is significantly lower due to heat pumps operating with a smoother profile keeping a 24h constant buildings temperature (HP contribution is 0 if the system hourly peak demand is during an hour without any heat pump consumptions). This operational mode also presents a slightly lower total energy consumption due to a more efficient heating system usage.

It is clear from this results how heat pumps operational dynamics will be a key factor to limit rising peak demand and thus the requirements for extra supply capacity or grid interconnections. For Set A the morning higher electricity demand could be reduced by, for instance, using local thermal storages, coordinating the heat pumps starting time through smart management systems or keeping a more stable temperature throughout the day, as shown in Set B.

Looking at how this translates on average on an hourly basis for the whole EU, as deductible from the previous table, again emerges a big difference between the electricity hourly contributions from heat pumps in Set A vs Set B. For both operational modes heat demand is significant during winter months, small in spring and autumn and negligible during summer time. Scenario 2 is not depicted as in terms of hourly profile it follows the same shape as Scenario 1.

Figure 23. EU average seasonal hourly electricity demand profiles in Scenario 1 for Set A and B (hourly total and heat pump % share of total grid demand)

Source: own estimation.

As mentioned above, the rapid deployment of electrified heat pumps in Europe poses some risks to the electricity grid, in particular driven by rising peak hourly demand. Additional risks emerge due to the distributed nature of heat pump systems which will add pressure at the grid distribution level. These risks include grid congestion, overloading of local substation transformers, voltage fluctuations and increased line losses. The potential high power demand of heat pumps at peak hours can strain transformers, leading to failures and power outages at the local level. Voltage fluctuations during peak utilisation hours can affect grid stability and damage equipment. Increased line losses and grid congestion due to the local grid infrastructure not adequately designed to handle the increased demand can result in inefficiencies and localised disruptions.

To mitigate these risks, upgrades to distribution infrastructure, such as transformers and power lines, along with smart grid technologies, will be necessary. The implementation of smart grid technologies and effective load management strategies can also contribute to limiting peak heat pump power demand and reducing the need for extensive grid reinforcements. Proper planning and coordination between stakeholders will be crucial for a smooth integration of heat pumps into the distribution network while maintaining reliability and resilience.

3.3 Heat pumps and flexibility

Energy flexibility in buildings can be described as a missed opportunity with high potential. By using the integral controls of heating, ventilation, and air conditioning (HVAC) systems, it is possible to steer the energy usage in a desired direction, without hindering indoor comfort. Moreover, by aggregating the potential flexibility of multiple buildings, it can be leveraged as a valuable resource in the operation of the wider energy system, such as limiting peak demand or providing demand response services to the power grid. Heat pumps will become one of the largest consumers of electricity in buildings and thus a key technology in enabling this potential.

Heat pumps offer similar control technologies as a boiler, including a control panel, thermostat and the possibility to monitor and schedule the consumption. In addition, as most heat pumps are electric, the ability to control is even more dynamic. Smart building technologies (e.g. building management systems, smart meters, and thermostats) further increase the possibility to control the energy flows and utilise the integral flexibility of heat pumps.

The flexibility potential is considerably higher if combined with a storage system, which can be electric or thermal. For this purpose a heat pump can also rely on the building's integral ability to maintain heat or cold, also known as building thermal inertia which can be increased by insulation. The flexibility potential can then be a combination of the building inertia and an associated storage means (ifeu, 2023). Thermal insulation reduces the heat transfer by using materials with low thermal conductivity. The ability to absorb, store heat and cold and slowly release it (thermal inertia) is given by the thermal mass of the building, i.e., materials with high density and specific heat capacity, generally found in the structure of the envelope (e.g. bricks). The key would be a combination of thermal insulation and thermal inertia (Verbeke & Audenaert, 2018). Finally, having a heat pump in a system in conjunction with a solar photovoltaic system and electric vehicles increases even more the potential for flexibility through smart load management and self-generation.

The increasing integration of intermittent renewable energy sources into the energy supply can result in instability in power systems, leading to imbalances, inefficiencies, and high costs if not properly managed. An underutilized solution to mitigate these negative effects is to utilize demand-side flexibility. Connection the heat pump and building to the wider electricity system make it possible to engage in time-of-use tariffs schemes and participate in demand response activities.

Heat pumps used for demand response schemes can be controlled directly by a third party (most often the energy supplied/grid operator) or indirectly where time-of-use tariffs are taken into account by the heat pump or building management system. One study analysed the potential of reducing heat pumps' electricity consumption during the peak hour given three different control strategy: lowered air temperature setpoints, lowered flow temperature and blocked heat pump compressor. The result showed a 55–90% electricity reduction during the peak period, where the effectiveness depended on how the control strategy affected the heat pump and the rest of the heating system (Crawley, et al. 2023). Another report analysed the demand response potential of 300 heat pumps and concluded it yielded possible load reductions of 40–65% (Müller and Jansen 2019). Several demand response strategies for residential heat pumps have been implemented or piloted, including in Germany where it is possible to get a favourable tariff from the utility company, contingent you grant them access to the heat pump and allow them to shut it off or lower the temperature during peak hours.

A German study looking at heat pump's load shifting potential of "smart grid heat pumps", concluded the potential was between 0.18 and 10.68 kWh per unit and operation cycle. Extrapolated to a pool of one million heat pumps, it's possible to shift up to 4 to 14 GWh hourly (Gunther, et al., 2020). Demand response flexibility strategies can alleviate a considerable portion of the stress the heat pump deployment will cause on the power grids. The thermal inertia of buildings, i.e. their ability to maintain heat or cold inside, allows us to move heat pump consumptions outside the peak demand hours.

In other words, heat pumps can play a key role in 'smart buildings' and 'positive energy districts', concepts capturing the idea that buildings and districts do not solely consume energy but also produces and stores energy. Smart appliances, including heat pumps, enable buildings and districts to use energy more efficient and increase the flexibility of the energy system. The European Commission has taken several actions to enable actors to utilise this potential. Among others, an optional smart readiness indicator rating was launched scoring building's capacity to accommodate smart-ready services. Furthermore, to streamline the standards for data sharing among appliance and define interoperability requirements, a Code of Conduct ([62]) was proposed to the energy smart appliances manufacturers. The adoption of buildings flexibility potential is still at its emerging stage. The rapid deployment of heat pumps will further increase this untapped potential.

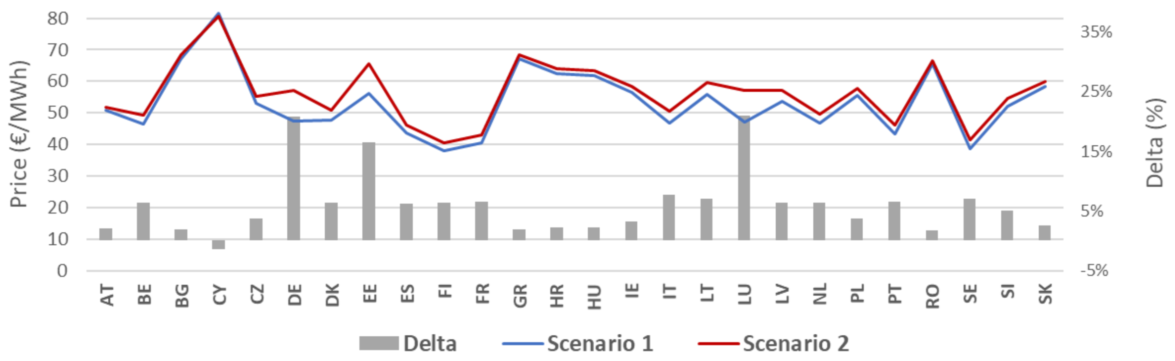
3.4 Electricity market prices

The electrification of heating has the effect of increasing the electricity total demand in the system which is met by different generation technologies with different production marginal prices. In a market with limited supply options, it is thus expected that a rise in electricity needs can boost wholesale prices, especially during hours of higher demand. In this section we take a look at the impact of the two different scenarios and operational heat pump modes on EU power market electricity prices.

The annual average wholesale electricity prices in 2030 are higher in Scenario 2 compared to Scenario 1 driven by higher total demand and higher load during evening hours. This is most visible in Germany and Luxembourg with values close to 20% higher, Estonia 15% and Sweden 7%. The increase in prices is a signal that the supply side of the market is tight and additional thermal capacity needs to be dispatched to fulfil the higher demand.

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

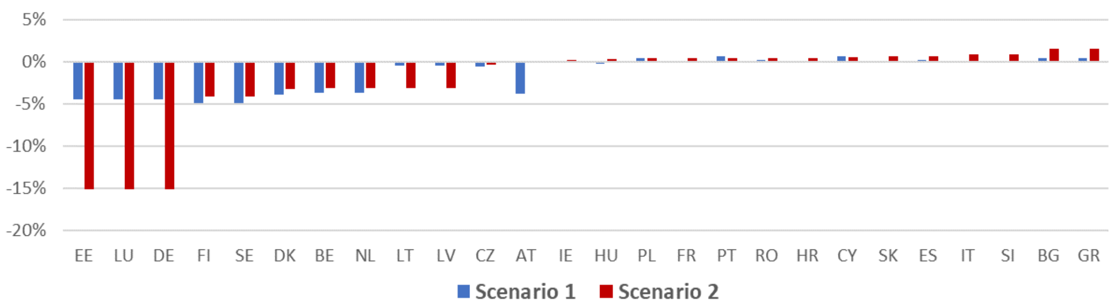
Figure 24. Average annual country level electricity prices in Scenario 1 and 2 in Set A



Source: own estimation.

For both Scenario 1 and 2, the heat pumps operational modes defined in Set B – with a more stable hourly profile - produce lower prices during daytime hours and increase them during night time. For half of EU countries this effect balances out on an annual basis with prices on average almost the same when comparing Set A and B. The picture is different for the other half of EU countries, especially those at norther latitudes. Countries such as Estonia, Luxembourg, and Germany have on average 5% and 15% lower prices in Set B in Scenario 1 and 2. This can also be observed in Finland, Sweden and Denmark with values around 5% lower. This is most likely driven by the effect of the load shape with lower prices during daytime and only a limited increase during nightime. This signals that the system in these countries is quite tight during morning and central hours of the day but has spare cheap generation capacity during off peak hours.

Figure 25. Set B annual price relative difference compared to Set A in Scenario 1 and 2

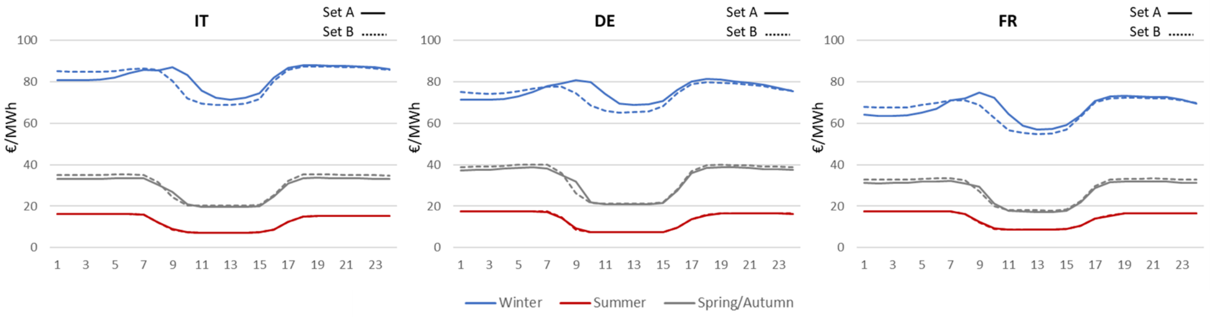


Source: own estimation.

This deduction is confirmed when looking at the average hourly prices for a sample of EU countries - Figure 26. We can see that for all countries Set A presents in winter higher prices during the central hours of the day but lower prices during night hours. This effect is almost negligible during the rest of the year due to the limited heat pump electricity load compared to the total grid demand. Scenario 2 is not depicted as it broadly follows the same hourly shape for all countries, with the exception of demand being a bit higher as shown in the previous sections.

The magnitude of the price change in each country depend from the supply side availability and marginal technology type. Following the market merit order dispatch mechanism whereby gas is usually the most expensive technology followed by coal and lignite, when demand rises it is often met by additional thermal capacity which pushes up the marginal price.

Figure 26. Average seasonal hourly electricity prices in Scenario 1 for Set A and B for a sample of countries



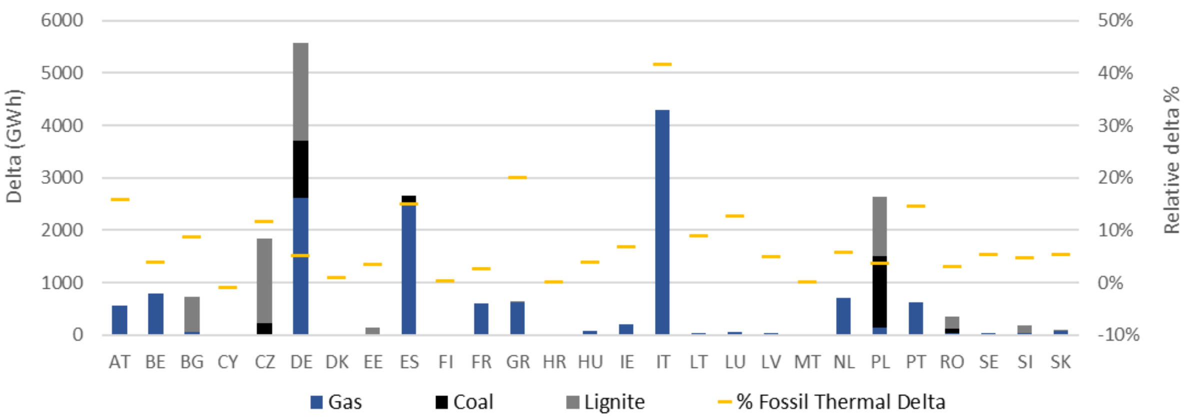
Source: own estimation.

3.5 Electricity market generation

In the wholesale electricity market, non-dispatchable sources, such as wind, solar, nuclear and run-of-river hydro, are dispatched first in the merit order mechanism, since their marginal cost of generation is lower than fossil-based power plants. When electricity demand is higher than the supply that these assets can provide, flexible thermal assets based on fossil fuels or biomass can be dispatched to meet the residual load.

Overall electricity generation is higher in Scenario 2 compared to Scenario 1 due to the relative higher demand. For this reason, additional dispatchable fossil fuel generation contributes to the increase with gas as the leading energy source. As shown in **Figure 27**, the countries with the highest relative increase are Italy and Greece, which are highly dependent on gas as last marginal technology. Germany, Italy and Poland lead in terms of absolute increased generation volume which in part is aligned with the increase in heat pump demand in this scenario. Poland, Czech Republic fossil-based generation increase is also driven by their cheaper than average electricity supply, based on coal and lignite which is then exported to interconnected neighbouring countries.

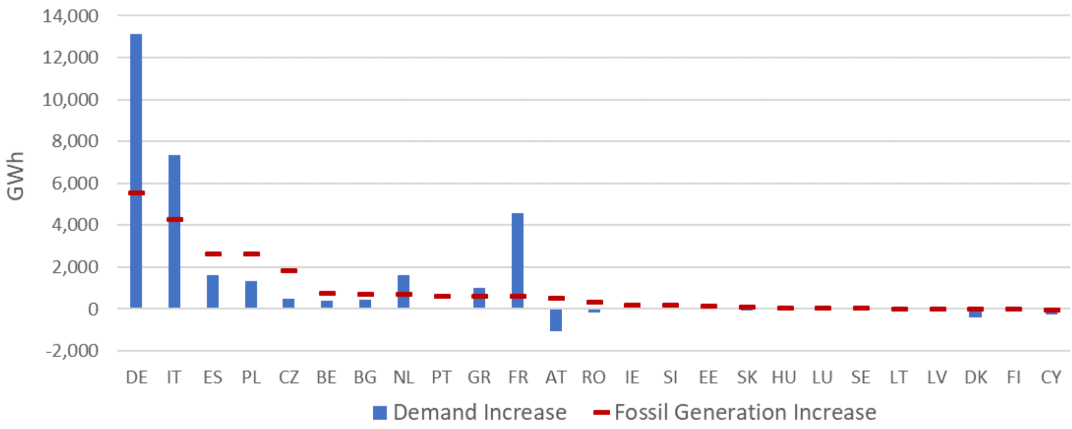
Figure 27. Scenario 2 total annual additional fossil fuel thermal generation in absolute and relative term to Scenario 1



Source: own estimation.

This phenomenon is most noticeable when comparing the increase in country electricity demand against the increase in fossil fuel generation. Two factors are driving the differences between EU Member States. Firstly, the EU is an interconnected market, where countries with a lower price generation stack based on coal and lignite have a higher increase compared to highly gas reliant countries, such as Czech Republic and Poland. Secondly, countries with a tight supply demand balance rely on the latest marginal technology available, which for most central EU countries is gas increasing fossil fuel generation. We can see this effect in countries such as Italy, Greece, Spain and Portugal. Finally, almost 1/3 of the increase in demand is covered by an increase in output from nuclear power plants especially from France and Finland.

Figure 28. Scenario 2 vs Scenario 1 increase in total country demand and fossil fuel generation



Source: own estimation.

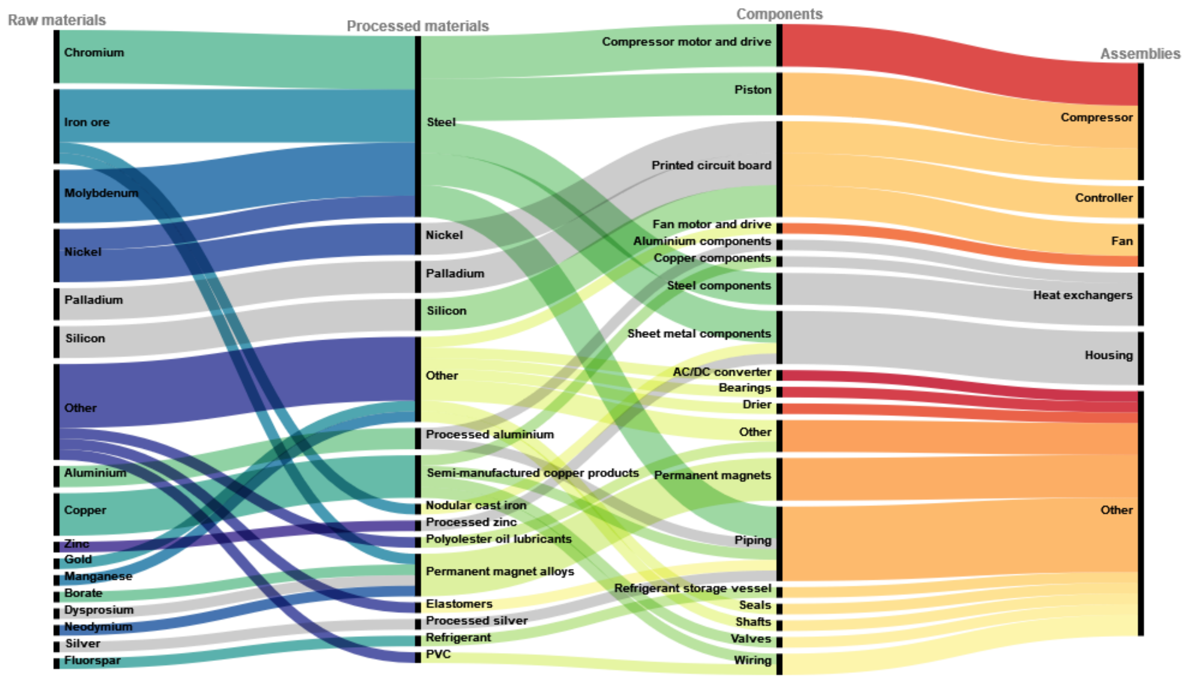
4 Potential bottlenecks

The EU heat pumps sector is growing fast to keep up with the rapid growth in demand. However, there are still barriers that might hamper this growth, such as volatility in material prices, the availability of semiconductors, financial turmoil, and the lack of skilled experts throughout the value chain. This chapter discusses potential barriers and solutions in the supply chain, skills development and refrigerants.

4.1 Supply chain

The compressors and housing of a heat pump are typically made from reinforced steel, while the 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 (ethylene, propylene or vinyl-chloride monomers) and cables are insulated with polyvinylchloride (PVC) (**Figure 29**).

Figure 29. Heat pumps materials, components and assemblies



Notes: This chart is for illustrative purposes and the supply chain varies depending on heat pump type and model. Printed circuit board includes semiconductors.

Source: own illustration.

Refrigerants for compression heat pumps can be 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 ammonia (GWP 0.1), water, methanol, carbon dioxide (GWP 1) or propane (GWP 0.02) ([63]). 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 underway, as a result of industry implementing the F-Gas Regulation (European Commission, 2022). See also the section on refrigerants below.

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

Semiconductors are used in heat pumps in several ways. The controller most obviously, but also in compressors, pumps and fans. Direct current (DC) inverters, DC pumps and DC fans all rely on printed circuit boards (PCBs) and semiconductors.

In monetary terms, the components accounting for significant portions of the total value of an air-source electric heat pump are the compressor (~25%), controller (~25%), heat exchangers (~15%), housing (~13%), valves (~10%), fan (~5%), pipework (~2%) and refrigerant (~2%) (Eunomia Research & Consulting,, 2020).

4.1.1 Material demand

Heat pumps are manufactured from similar raw materials as that of the boilers they replace. 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 boilers, air conditioning, and refrigeration manufacturing. Compared to a gas boiler, a heat pump uses a greater quantity of copper, some additional materials, and notably a refrigerant (**Table 5**).

Table 5. Material needs for replacing gas boilers with air-source heat pumps.

	Air-source heat pump (kg)	Gas boiler (kg)	Difference (kg)
Polyester oil	2.7		2.7
R-134a	4.9		4.9
Rockwool		8	-8
Low-alloyed steel	32	115	-83
Reinforcing steel	120		120
Stainless steel	5	5	0
Copper	36.6	3	33.6
Aluminium		7.5	-7.5
Brass		0.1	-0.1
PVC	1.6		1.6
HDPE	0.5	0.9	-0.4
Elastomers	16		16
Total	219.3	139.5	

Source: JRC based on (Sevindik, Spataru, Domenech Aparisi, & Bleischwitz, 2021).

Note: Bills of materials are representative. For example, air-water heat pumps used R410a in the past as well as R134a. More recent models use R32, propane or other refrigerants, and have more compact designs.

4.1.2 Supply chain vulnerabilities

Heat pumps do not have specific materials exposures (Artelys and Trinomics,, 2021) but are vulnerable to volatility in metals prices, the global shortage of semiconductors and the import dependency on permanent magnets. The metals prices, which reached very high levels in 2021, later declined to more customary levels. Volatile prices increase the risk for manufacturers, as they increase their costs and may potentially jeopardise future deployment projections. The semiconductor (chip) shortage is a current barrier for several sectors and the EU has taken firm action to address the region's dependency. However, the chips used in heat pumps are not highly specialised or advanced, which means they can sometimes be sourced or repurposed from adjacent manufacturing sectors ([64]). Another economy-wide shortage is permanent magnets, which is a potential risk

([64]) For more detailed discussion, see for example www.eceee.org/all-news/news/chip-shortage-adds-to-europes-heat-pump-supply-woes.

because there are few short-term solutions to a disruption to imports from China. A discovery of the rare earth metals used in such magnets was announced in Northern Sweden in 2023 but these won't reach market in the near future ([65]).

Heat pumps are often manufactured in the EU. Compressor design and manufacturing is a specialised activity that has become dominated by a small number of suppliers from outside the EU, though there are also several European players. Manufacturing of other mechanical components, such as heat exchangers, housing and controllers, is less specialised (i.e. they are also used in other products) and distributed among a wider range of companies worldwide, including in Europe (Lyons, et al, 2022).

In the longer term, recycling and substitution can be effective strategies. For example, to address volatility in the supply of semiconductors, manufacturers could revert to simpler designs, such as alternating current fans. This is an area of increased focus for the European Commission and is the subject of recent work by the JRC ([66]).

In the short term, some stakeholders see a rapid F-gas phasedown as a bottleneck. However, in the medium term, the transition to a 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.

4.2 Skills development and training

The upscaling of heat pump deployment is conditional on the enlargement, reskilling and upskilling of the workforce along the whole value-chain. The EU is facing a considerable skills gap in its labour markets, including in the construction sector.

The heat pump industry has grown to become one of the largest employers within the renewable energy sector in the EU, employing nearly 320 000 people (EurObserv'ER, 2021). The European Heat Pump Association estimates that at least 500 000 skilled workers are needed in 2030 to meet the increase in demand (EHPA, 2023), while European Heat Industries estimates that the whole heating and cooling sector needs 750 000 installers (ehi, 2022).

The rapid demand increase for heat pumps is expected to generate jobs throughout the value chain. Heat pump manufacturing takes place across the EU, driven mainly by small and medium-sized enterprises and often located in rural areas (Nowak, 2022). In the manufacturing stage, both production times and labour inputs are expected to decrease over time due to automated manufacturing processes.

The scarcity of skilled professionals can be alleviated by transferring skills from other sectors. Most obviously, installers of gas or oil boilers can be reskilled to also install heat pumps. The geographic location of the employment and the skills required are very similar, and many installers possess knowledge of both technologies already. It is less obvious that qualifications for drilling and trenching in the oil and gas industry can be reused to fit ground-source heat pumps (IEA, 2022).

There is a pressing need for skilled installers. Installers and energy experts play a key role in recommending heat pumps to households (EHPA, 2021). Customer acceptance and skilled installers are interdependent, and both are needed to achieve largescale deployment of heat pumps.

Ideally, the installer guides the customer in the selection and installation of the heat pump. The first step of the deployment of a heat pump is the quotation phase, which typically includes the energy survey of the home including the building performance, heated area, existing building insulation, source of energy, and state of the windows and radiators. The installer might also advise about the performance and cost of the heat pump, and potential need for associated energy efficiency upgrades in the building.

However, any interventions on the refrigerant-carrying circuit would require additional know-how and skills. In addition, there are legal requirements on training and certification that technicians have to comply with under the rules of the F-gas Regulation on activities such as installing, servicing, leak checking, recovering gas and decommissioning.

([65]) https://www.bbc.com/news/world-europe-64253708

([66]) See more in depth analysis of the material demand forecast in heat pumps, in the report: Carrara et al. (2023) Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study. https://publications.jrc.ec.europa.eu/repository/handle/JRC132889

Only F-gas-certified engineers can handle hydrofluorocarbon refrigerant gases (HFC refrigerants), leak test a system containing them and purchase HFC refrigerants. Under the new rules for F-gases, it is very likely that F-gas alternatives will also be covered by these obligations. Furthermore, any low GWP F-gases or their alternative have additional properties such as flammability, higher pressures or toxicity that installers and service technicians must be prepared and trained for.

Today most installers have been trained by manufacturers at their own training centres and programmes or by industry associations (ehi, 2022). Heat pump manufacturers train installers in their own training centres in the countries where they are present and where they are planning to expand their activities. They also collaborate with other key stakeholders, such as governments, industry associations and education institutions, in order to address the skills gap faced by the heat pumps sector.

Error! Reference source not found. In the formal education system, both as part of gas heating and plumbing apprenticeships as well as college courses, learning about heat pumps is likely to be limited (NESTA, 2022). Therefore, curricula of national vocational education and training (VET) and higher education systems need to be streamlined considering the current heat pump market needs reflected by training and courses organised by actors outside the formal education system. Skilled workforce supply in the heat pumps sector can be enhanced both by retraining existing gas engineers and plumbers, and by attracting new entrants (Weinhold, 2022).

Installers are often not sufficiently familiar and up to date with legislation and geographic (national, regional) variations thereof. Setting up a supervising body could help improve the inspection and correct functioning of installations by systematically monitoring heating and HVAC facilities.

The supply of skilled heat pump installers can be addressed through a combination of measures: focusing on both new entrants and retraining; encouraging companies to take and train new workers; integrating heat pumps in pre-existing certifications for heating, ventilation and air conditioning (HVAC), construction, and electrical professions; new, direct training pathways in heat pumps installation and design; incentives to attract HVAC professionals to gain additional certifications and periodic renewal thereof (as training may be high cost and not lead to wage premium); reinforcing manufacturer-run trainings and simplifying the installation process; internationally standardised certification schemes with broad curricula; and clear signals and engagement from governments, including national heat pump deployment targets and roadmaps, to build confidence and provide professionals with long-term employment prospects (IEA, 2022) (NESTA, 2022).

The European Commission made 2023 the European Year of Skills (EC, 2022a) to put the issue higher on the agenda, encompassing and reinforcing existing skills policy initiatives (Czako, 2022). The initiative also seeks to promote tools for increased transparency and easier recognition of qualifications, including those awarded outside the EU. In the context of the European Year of Skills, the European association of electrical contractors called upon the EU to launch an ambitious campaign to change mindsets about technical education (Beaufils, 2023). This would contribute to easing skills shortages in the clean energy industries in general.

The REPowerEU Plan encourages stakeholders to set up a largescale 'skills partnership' under the Pact for Skills to help address the qualified worker shortage (EC, 2022b). The need for systematic assessment of the gap between available and needed installation professionals at Member State level is also emphasized by the European association of electrical contractors (Beaufils, 2023). At national level they point out the need for incentives for technical education and apprenticeships, as well as more public-private partnerships (EHPA, 2022b).

4.3 Refrigerants

Heat pumps need refrigerants to work. Heat pumps transport energy by absorbing ambient heat and compressing the refrigerant, which increases its temperature, and releasing it into a building. The majority of heat pumps currently in use employ hydrofluorocarbons (HFCs) as refrigerants, a group of fluorinated gases (F-gases) widely recognised for their high global warming potential (GWP). The market share of heat pumps using (the less carbon-intensive) hydrofluro-olefins (HFOs) or (the low-carbon) natural refrigerants is growing rapidly. The industry is facing a challenge as the refrigerants used in heat pumps will have to be overhauled just when there is an urgent need for a massive scale-up in production.

Two current legislative processes will determine the future use of HFCs and HFOs in heat pumps, taking into account that an excessively rapid phase-out may halt the scale-up of heat pump manufacturing, while phasing out too slowly risks locking in emissions for decades to come:

- The F-Gas Regulation uses a quota system for HFCs to progressively limit high GWP refrigerants put on the EU market each year. A European Commission proposal to future-proof the regulation increases the ambition of the quota system (around 98% reduction by 2050 compared to 2015) and adds three relevant prohibitions for heat pumps limiting the GWP of the F-gases used in different heat pump systems ([67]).
- In a parallel proposal focusing on the environmental harm of certain chemicals, the national authorities of Germany, Denmark, the Netherlands, Norway and Sweden are proposing to restrict and phase out the use of per- and polyfluoroalkyl substances (PFAS)[68], affecting many fluorinated refrigerants, including HFOs and mixtures with HFOs. The legislative process is still on an early stage but if implemented as it current stands, it would leave natural refrigerants as the sole option for heat pump manufacturers.

F-gases make up around 2.5% ([69]) of the EU's total greenhouse gas emissions and have doubled from 1990 to 2014, in contrast with the decline of emissions from other sectors and gases. F-gases are potent greenhouse gases with a global warming effect of up to 25 000 times greater than CO_2. The conventional and most common HFC refrigerants have a GWP of around 2 000 (table 6). The EU's F-Gas Regulation ([70]) and international treaties ([71]) aim to reduce the warming effects of refrigerants significantly by phasing out the use of F-gases (including the HFCs). The potential is enormous as 0.5 degrees of global warming can be avoided if the agreed global measures are implemented. For example, a recent publication has shown that in the sector of small split air conditioning (which includes heat pumps), a transition from R410a (the conventional technology worldwide) to propane would avoid around 0.1 degrees of global warming (Purohit et al., PNAS, 2022) ([72]).

Table 6. Refrigerants and their GWP

	HFC					HFC/HFO blend		HFO		Natural	
Refrigerants	R410A	R407C	R134a	R466A	R32	R454B	R455A	R513A	R454C	R290 (Propane)	R744 (CO2)
GWP	2088	1774	1430	733	675	466	146	631	146	3	1

Source: European Chemical Agency (ECHA) Registry of restriction intentions until outcome. Available: https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b

The rapid increase of heat pumps in Europe and globally also increases the relevance of the emissions from refrigerants. Refrigerants can cause emissions during several stages of the heat pump's lifecycle, including production, installation, operation, maintenance and disposal. The emissions are caused by leakage and depend on several factors such as the model and maintenance. A recent study looking at different heat pump installations in the UK concluded that the average annual leakage rates of refrigerants were 3.5% for heat pumps in residential buildings and 3.8% for installations in non-residential buildings (BEIS, 2020). **Figure *30*** displays a comparison of emissions from heat pumps for three typical single-family buildings in three countries, taking into account their CO_2 emissions from electricity consumption and annual leakage of refrigerants. The overall emissions mainly depend on the electricity mix but the refrigerants represent a considerable share, with HFCs being responsible for 10% in Romania, 19% in Belgium, and 83% in Sweden. Three typical single family buildings are used for this illustration built between 1990-1999 (Romania) or 2000-2010 (Sweden and Belgium). The electricity consumption was calculated using EBEM model (see methodology). The data for carbon intensity of electricity comes European Environmental Agency and is from 2020.

([67]) (1) F-gases with GWP >=150 cannot be used in self-contained systems ("monoblocs") from 2025 onwards;. (2) F-gases with GWP>=150 cannot be used in small split systems from 2027 onwards; and (3) F-gases with GWP>=750 cannot be used in larger (i.e. capacity > 12kW) split systems from 2027 onwards. These rules are currently being negotiated, but there appears to be general support for giving clear signals to industry in this sector.

([68]) European Chemical Agency (ECHA) Registry of restriction intentions until outcome. Available: https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b

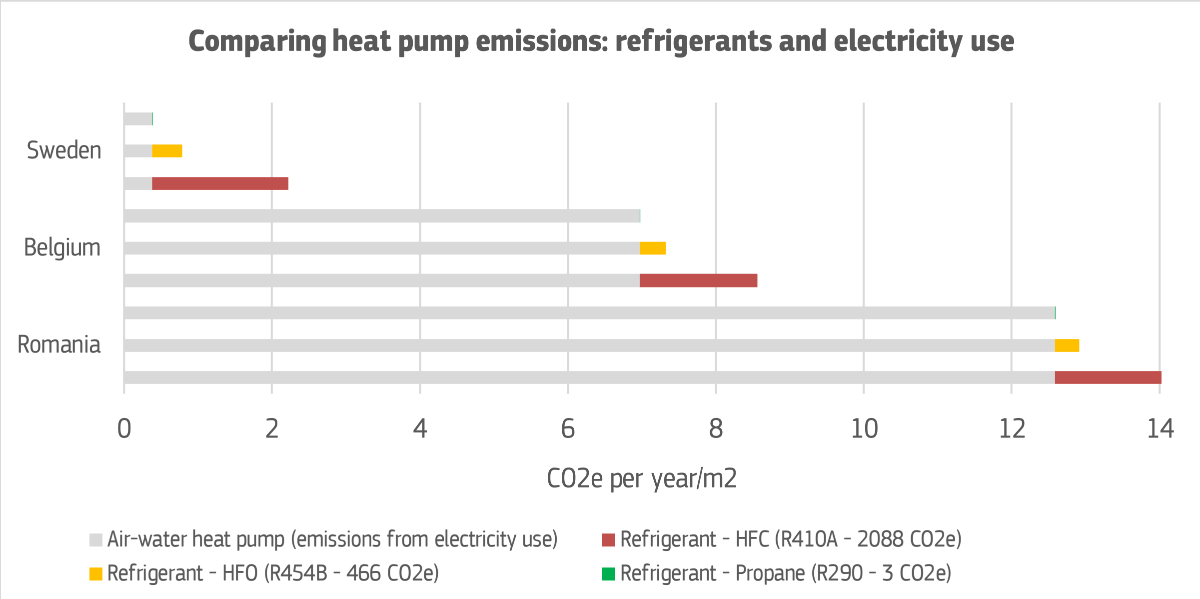
([69]) The gases are not only being used in heat pumps but in air-conditioning systems, refrigerators etc.

([70]) F-Gas Regulation (EC) No. 517/2014 went into effect on January 1, 2015. A revision of this Regulation is currently being negotiated (April 2022).

([71]) The Paris Climate Agreement and the Kigali Amendment of the Montreal Protocol.

([72]) https://www.pnas.org/doi/full/10.1073/pnas.2206131119

Figure 30. Heat pump emissions from refrigerants and electricity use. Comparison of three different single-family houses located in Belgium, Romania and Sweden.



NL: Three typical single family buildings are used for this illustration built between 1990-1999 (Romania) or 2000-2010 (Sweden and Belgium. The data for carbon intensity of electricity comes European Environmental Agency and is from 2020.

Source: own calculation and (EEA 2020)

Both the deployment of heat pumps and the phase-down of F-gases reduce emissions. The EU needs to balance the reduction of direct emissions from F-gases and facilitate an enabling environment for the scale-up of heat pumps as envisaged in REpowerEU. Taking this into account, the quota system in the proposal has been designed to provide sufficient time to allow for this rollout while quickly phasing out the use of F-gases. Not sufficiently addressing the HFCs in heat pumps risks locking in F-gas emissions for a considerable time, given that lifetimes are about 15 years and leakage tends to become more significant in older systems.

Industry associations, EHPA, EPEE, AREA and APPLiA, argue that a more rapid phase-down than in the current F-Gas Regulation would limit the growth potential of heat pumps (see for example EHPA, 2022b). Some individual manufacturers are of a different view, arguing that heat pumps using natural refrigerants (especially propane) are a mature and safe technology able to replace all residential heat pump types ([73]). The European Commission proposal has been designed to balance the two sides, allowing for the required heat pump growth, while preventing an increase in direct emissions from refrigerants. The prohibition dates were designed to allow enough time for manufacturing to adapt, although industry associations contend that the transition to more flammable substances presents significant additional complexities in terms of compliance and changes to building codes. In addition, the proposed F-gas Regulation includes some exemptions, including when required to comply with safety standards.

In the medium term, the transition to greater use of natural refrigerants can be an opportunity for the industry to differentiate itself with respect to non-EU competitors and to reduce dependence on non-EU suppliers (Lyons L. , et al., Clean Energy Technology Observatory: Heat Pumps in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets, 2022). The EU heat pumps sector is globally well established and highly innovative. It is well positioned to benefit from increasing deployment of advanced heat pumps that are "future proofed". Natural refrigerants may thus have an advantage in terms of price trend and price stability, and they are not patented. At the same time, the system cost for heat pumps using natural

([73]) Hydrocarbons21 (January 12th, 2023) ATMO Europe: F-Gases No Longer Needed for Residential Heat Pumps, Says Viessmann. Available: https://hydrocarbons21.com/atmo-europe-f-gases-no-longer-needed-for-residential-heat-pumps-says-viessmann/

refrigerants is currently slightly higher [74] (ATMOsphere, 2022). The industry has already started to adjust, with examples of production lines being reconverted, and new ones started, to focus on natural refrigerants. The phase out of F-gases also reduces the EU's reliance on imported refrigerants, since most HFCs are imported from China (Cheng and Lauly, 2022).

[74] One study concluded based on interviews with industry stakeholders that the additional production cost was 10-15% for heat pump using natural refrigerants (ATMOstphere, 2022). However, the smaller production scale and the fact R290 often are considered premium heat pump systems, make a direct comparison difficult.

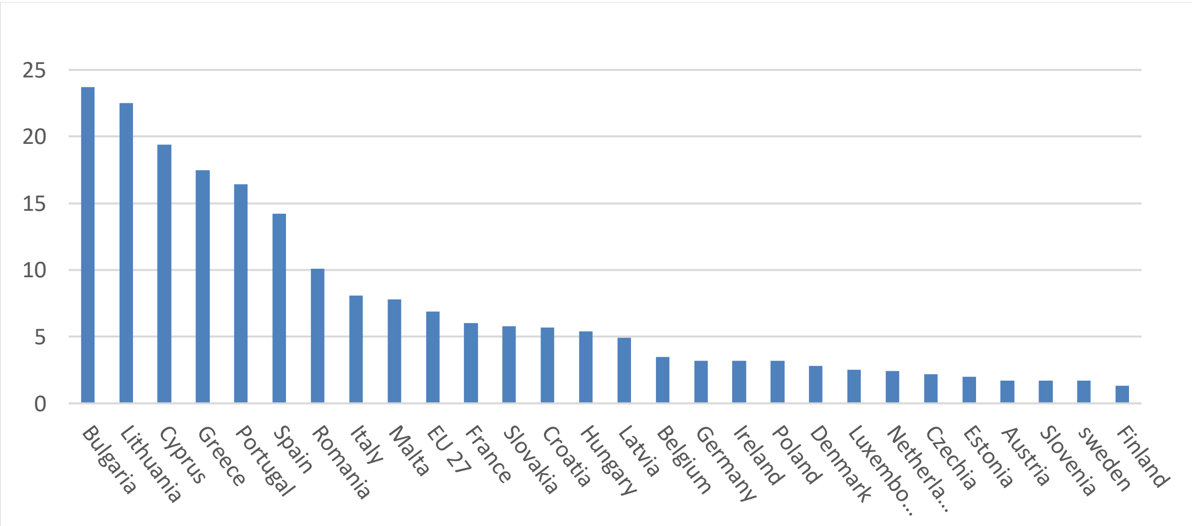
5 Vulnerable households and heat pump adoption in EU

The effects of the pandemic and the war in Ukraine led to soaring energy prices across Europe, intensifying the problem of energy poverty. 35 million people (approximately 8% of the EU population) were unable to keep their homes adequately warm in 2020, the highest number in seven years (**Figure 31**). Moreover, other vulnerable social groups are on the verge of, or experiencing, hidden energy poverty as 21% of EU's population (approximately 95 million people) is at risk of poverty or social exclusion (Koukoufikis & Uihlein, 2022). These social realities create both threats and opportunities for the adoption and mainstreaming of heat pumps as a more sustainable domestic heating and cooling solution.

Heat pumps and energy efficiency of buildings are long-term solutions to energy poverty, as the higher efficiencies make utility bills more affordable and predictable.. A heat pump is on average around three times more efficient than a gas boiler, reducing vulnerability to energy prices. The opportunity is greater for households in countries with affordable electricity tariffs, where, in combination with higher prices of oil and gas, the payback period of the heat pump installation becomes shorter.

Nevertheless, investment costs and high electricity prices in several Member States constitute the main barrier for further adoption of heat pumps. Installation requires significant upfront investment, as the cost of purchasing and installing a system will cost between EUR 1 000 and EUR 20 000, depending on the type of heat pump, thermal power and the size of the space that needs heating. This upfront cost is significantly higher when compared with other heating solutions, and modifications are often also needed to the existing system (radiators, pipes etc.) to accommodate the installation. Moreover, poorly insulated houses need to improve their building energy performance, for example with additional thermal insulation, before the heat pump can work optimally, further swelling the costs. Beyond that, the technical characteristics of a building, its tenure and proprietary status, the local planning codes, and the lack of localised cost/benefit over the productivity and cost savings of the system are barriers that need to be overcome for faster adoption.

Figure 31. % of EU population unable to keep home adequately warm by country, 2021



Source: Eurostat, EU-SILC survey [ILC_MDES01]

The four key factors affecting the potential of households to switch to heat pumps as a main heating source are:

— the financial ability to purchase the new system;

— the household's general ability to participate given their tenure status;

— the housing unit's ability to accommodate a new system given the building's design and the planning regulations in the area; and

— the affordability of electric energy to operate it adequately.

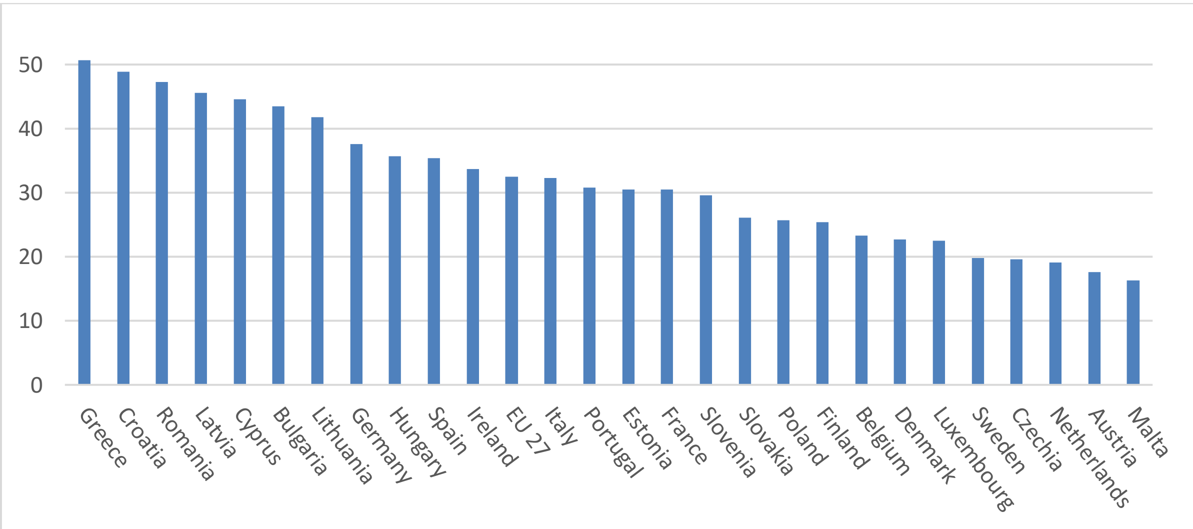
To assess the impact of these factors on future installation rates and associated social issues, we need to consider the available economic and social data.

In 2020, almost one in three people in the EU (32.5%) were not in a position to face unexpected financial expenses such as costs for a medical emergency, or for replacement of household machinery or a car (**Figure 32**). This share of the population occupies approximately 63 million dwellings ([75]) and consequently, without any financial support, these households are unable to afford the acquisition and installation of a new heating system.

However, financial capacity is only one of the barriers to the adoption of heat pumps. Split incentives for building owners and tenants represent a major non-financial barrier to the further adoption of heat pumps. The proprietor often neglects to invest in energy efficiency since the utility bills are usually paid by the tenant. The tenant can only make energy consumption-related decisions but cannot invest in the building's energy envelope, thus bearing the costs of the energy-inefficient accommodation.

In the EU, 30% of households rent their primary dwelling either at market or at reduced rates (**Figure 33**). Thus, without innovative policymaking that can address the split incentive problem in a just way, the installation rates of heat pumps in these properties will remain low, resulting in high energy usage, utility bills and carbon emissions. The REPowerEU plan envisages a doubling of the yearly rate of deployment to install 30 million heat pump systems, replacing gas and oil boilers, by 2030. Without dedicated policies and financial support targeting these groups, many dwellings occupied by vulnerable households may not be able to participate in this transition.

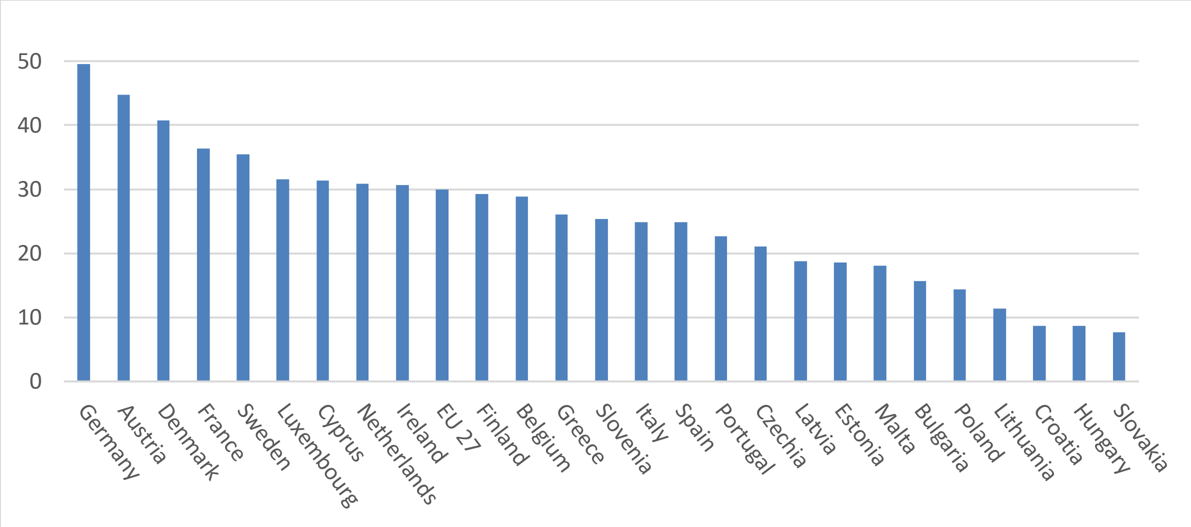
Figure 32. % of households with no capacity to face unexpected financial expenses, 2020



Source: JRC, based on EU-SILC data

([75]) JRC analysis on EU SILC data

Figure 33. % of households renting their dwelling, 2020



Source: JRC, based on EU-SILC data

Using 2019 data, **Table 7** quantifies selected household groupings based on needs-driven (energy poverty) and capacity-driven (financial stability and ownership status) factors. Cross-referencing these provides a qualitative assessment of the ability, need and potential of households to invest in heat pumps.

Table 7. Vulnerable households and potential of heat pump installation

			Tenure status	
	% of households to total EU	**Estimated number of occupied dwelling** '000	**Rented or other** (%)	**Privately owned** (%)
Energy poor households ([76])	9.9	19,354	(29.1) 5,632	(70.9) 13,722,000
Households with limited financial capacity ([77])	30.7	60,206	(33) 19,867	(67) 40,339
Households financially stable and non-energy poor	66.4	130,048	(18.8) 24,449	(81.2) 105,599
Households financially stable but energy poor	3.3	6,550	(19) 1,244	(81) 5,306

Source: JRC, based on EU-SILC 2019 data

Tailor-made financial support schemes and policy programmes for residential heat pump adoption are needed to distribute the cost-saving benefits of this technology fairly. These can include various measures to replace heating systems, e.g. direct subsidies and interest-free loans, or incentives to support high electricity costs during operation, e.g. winter electricity price caps or VAT rebates for households that use heat pumps as the

([76]) Households with arrears in utility bills or unable to keep the home adequately warm, EU-SILC 2019
([77]) Households with no capacity to face unexpected financial expenses, EU-SILC 2019

main heating generator in the household. Information campaigns explaining the cost benefits of heat pumps should be used to incentivise the 5.3 million financially stable but energy-poor households to switch to a more efficient energy system. Financial support ([78]) is needed for the 40 million privately owned and owner-occupied dwellings of financially vulnerable households. For the 60 million rented dwellings, regardless of financial status, innovative urban planning and housing policy intervention is required to tackle the split incentives problem.

The European Commission and its Member States have taken several measures to address these issues. The EPBD proposal asks Member States to present an overview of national policies and measures empowering and protecting vulnerable households, alleviating energy poverty and ensuring housing affordability in their National building renovation plans ([79]). To overcome the split incentives dilemma, the same proposal includes the implementation of minimum energy performance standards, obliging the landlords of buildings classified as worst performing to improve the energy performance class of the buildingitis. Furthermore, in relation to the revision of the EU Emissions trading system (ETS), a Social Climate Fund will be enacted with the main purpose of supporting vulnerable households, through direct income support and support for measures that reduce emissions in transport and building sector ([80]).

([78]) Albeit a too high financial support will induce an increase of the price.
([79]) https://eur-lex.europa.eu/resource.html?uri=cellar:c51fe6d1-5da2-11ec-9c6c-01aa75ed71a1.0001.02/DOC_1&format=PDF
([80]) https://climate.ec.europa.eu/eu-action/european-green-deal/delivering-european-green-deal/social-climate-fund_en

6 Competitive position of EU companies

The accelerated rollout of heat pumps, as set out in REPowerEU, presents both a challenge as well as an opportunity for the EU heat pump industry. In 2021, the European market was already the fastest growing and biggest export market globally. With ambitious targets, this growth is expected to further accelerate and it is important that the industry remains competitive in order to reap the benefits in terms of value creation and jobs (Lyons, et al. 2022) (IEA, 2022).

6.1 EU positioning in current markets

In 2020, the heat pump sector employed nearly 320 000 people ([81]) in the EU. Most jobs were in large heat pump markets, such as France, Italy, Portugal and Spain. These countries are mostly active in reversible air-to-air heat pumps, which are primarily used for cooling. It is, however, impossible to differentiate the data by end-use ([82]). Assuming cooling accounts for approximately two thirds of the EU market, heating-only jobs account for over 100 000 jobs. This is in line with estimates from the EHPA ([83]), which estimates nearly 120 000 jobs, with 37% of them in the manufacturing sector (EHPA, 2022). More importantly, the sector has experienced a significant increase in jobs since 2017.

The European heat pump industry is well established, innovative and the global leader in most heat pump segments (air-water, ground-water and brine/water-water). The EU industry consists of many small and medium enterprises, and a few larger manufacturers. However, no single company dominates the market in Europe. A few noteworthy consolidations have taken place recently: Midea (China) acquired a majority stake in the Italian Clivet group, Stiebel Eltron (DE) took over Danfoss Varmepumpar (DK), Hisense (China) acquired Gorenje (SI), and Nibe (SE) acquired Waterkotte (DE). There are around 170 heat pump factories in Europe, with the majority being assemblers only, and not also component manufacturers (Lyons L. , et al., 2022). There are around 130 heat pump assemblers and as many as 15 companies generating 80% of the total revenue, indicating that the industry is characterised by a big number of players ([84]).

There are fewer component manufacturers, and these consist of larger companies which also produce components for other industries ([85]). The turnover of the EU heat pump sector amounted to EUR 41 billion in 2020, with France, Italy and Germany generating the most, according to EurObserv'ER. As noted above, about one-third should be attributed to heating, as Mediterranean countries use air-to-air heat pumps mainly for cooling. This is in line with the EHPA's estimate of the total market value in 2021 ([86]) of almost EUR 15 billion (EHPA, 2022). As with employment, turnover grew by an average 7% per year during the 2015-2020 period, and the growth is expected to be even stronger in 2021-2022 according to early data. Many of the heat pumps sold and installed in Europe are also manufactured in the EU, with only compressors largely imported from China, creating a potential supply risk. Nevertheless, a large part of the value creation in the heat pump value chain remains within the EU.

Demand growth has spurred EU manufacturing, which recorded the highest ever year-on-year increase of 30% in 2021, reaching EUR 3 billion in production value, according to Eurostat Prodcom data. Sweden has reclaimed its position as the biggest producer, ahead of France and Germany, although France has yet to disclose its value for 2021. Production also increased in Spain, Italy and Finland, while many countries did not disclose their figures in 2021. This indicates that the EU has a solid manufacturing base. However, it is yet to be seen whether the European industry is able to scale up fast enough to meet the soaring demand. Several companies have announced the expansion of their production lines: StiebelEltron is investing EUR 600 million to triple production by 2025; Viessman is investing EUR 1 billion in development and a new production site in Poland; Vaillant is investing EUR 130 million in Slovakia; Panasonic is looking at increasing production in Czechia (EUR 145 million);

([81]) This includes both direct and indirect employment. Direct employment refers to equipment manufacturing, installation and operation and maintenance. Indirect employment refers to secondary activities such as transport and other services.

([82]) Reversible air-to-air heat pumps are included in the numbers reported by EurObserv'ER, but it is impossible to differentiate the data by end-use. Therefore, part of this market falls into the scope of Cooling. Especially countries such as France, the Netherlands, Italy, Spain and Portugal include a sizeable proportion of reversible air-to-air heat pumps in their statistics as they meet performance criteria bybySet By the Renewable Energy Directive. In contrast, Germany and Austria, do not include reversible air-to-air heat pumps in their statistics.

([83]) EHPA focuses on heat pumps, covering 19 EU countries and the UK and Switzerland.

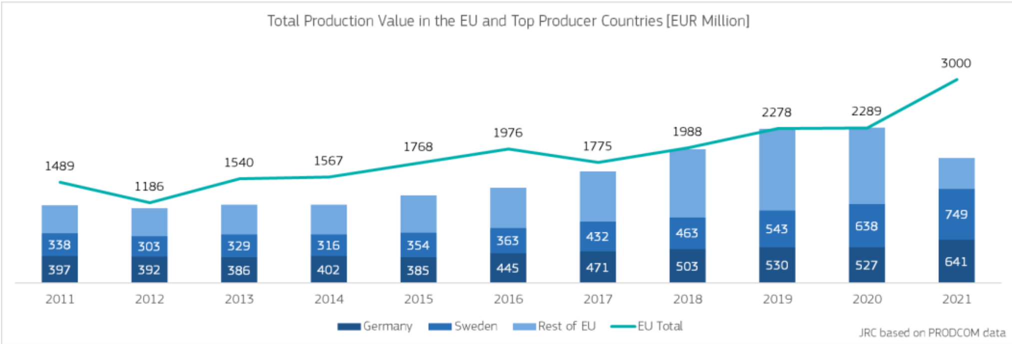
([84]) JRC elaboration based on EHPA manufacturers and company financial reported in Orbis.

([85]) JRC elaboration based on EHPA manufacturers and company financial reported in Orbis.

([86]) EHPA focuses on heat pumps, covering 19 EU countries and the UK and Switzerland.

Bosch is investing EUR 355 million; NIBE is investing EUR 460 million in Sweden; and Daikin Europe is planning to invest EUR 1.2 billion at four different production sites by 2025, including opening a new site in Poland (IEA, 2022). In total the announced investment amounts to EUR 4 billion.

Figure 34. EU production value and top producers disclosing data among the Member States [EUR million]



Source: JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard (CIndECS) (Draft, 2023)

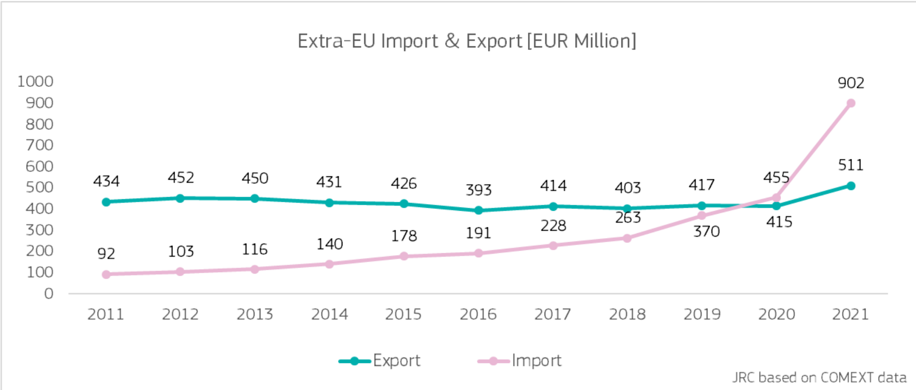
The new manufacturing factories coming online, especially those in Europe where labour costs are higher than in Asia-Pacific, can benefit from improved labour productivity through digitalisation and automation. For example, innovative sensor controls and programming can streamline manufacturing processes and increase the efficiency of assembly lines, while modular designs and standardised components compatible with different types of heat pumps and 3D printing can reduce manufacturing times (RHC and EHPA, 2021). Essentially this also means a slower growth in manufacturing jobs in Europe. In the period 2015-2021, heat pump assemblers in the EU already improved their productivity in terms of generated turnover per employee by 32%, as turnover grew faster than employment ([87]). On the other hand, installing a heat pump takes twice as long as installing a boiler, and there is therefore still significant potential for job creation.

Extra-EU exports of heat pumps remained relatively constant between 2011 and 2021, at EUR 500 million in 2021 (**Figure 35**). During the same period, however, extra-EU imports grew, reaching over EUR 900 million, indicating a penetration of non-EU producers, mainly from China, to the growing EU market. Thus, since 2020, the EU trade surplus has turned into a trade deficit, further increasing in 2021. France is the biggest exporter globally, followed by Germany and China. Nevertheless, France, which has historically had a strong trade surplus, has seen a quickly deteriorating trade balance. Meanwhile, Sweden and Czechia have growing trade surpluses, which indicates that their production, especially that of Sweden, is increasingly channelled towards exports. Swedish producers are mainly serving neighbouring markets such as Germany, Finland, the Netherlands and Denmark. EU internal trade plays a significant role in EU countries' exports, so some of it is re-exporting. The EU is fairly well positioned in the export market, as there are not many export opportunities that EU countries are not capturing, except for the US, Australia, Chile and United Arab Emirates, where imports from non-EU countries are outpacing those from EU countries. Nevertheless, non-EU export opportunities are small compared to the EU Single Market, which is the biggest export market for Member States. In 2021, about 73% of heat pump sales by value in the EU were manufactured here ([88]) (JRC, commissioned by DG GROW - European climate-neutral industry competitiveness scoreboard (CIndECS) (Draft, 2023).

([87]) JRC elaboration based on EHPA manufacturers and company financial reported in Orbis.

([88]) This is based on JRC calculation based on production from Prodcom and imports and exports from UN Comext data. This should only be used as an approximation as production and trade values are not entirely comparable.

Figure 35. Extra-EU import & export [EUR million]



Source: JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard (CIndECS) (Draft, 2023)

6.2 EU positioning in innovation

Further innovation is key to maintaining competitiveness in the growing market, continuously improving product performance and to sustainability. Innovation is a precondition to meeting climate neutrality and boosting the technological sovereignty of the EU.

EU public R&D investment continued to grow in 2020, with Austria, the Netherlands, Denmark, Germany, France, Belgium and Spain being among the top 10 global investors Although funding for heat pumps is limited compared to some other clean energy technologies, the EU spends a significant amount on public R&D relative to several major economies worldwide. Globally at the country level, Japan is the biggest public investor ([89]). In addition to Member State funding, the EU supports R&I through Horizon Europe, the Innovation Fund, Interreg and LIFE. Under Horizon 2020 and Horizon Europe framework programmes (2014-2022), the largest recipients of EU funding were Spain, Germany and Italy (Lyons L. , et al., 2022).

The venture capital investment directed at start-ups and scale-ups has also increased significantly in the past five years (2016-2021) compared to the previous period (2010-2015). Early-stage investment has grown sevenfold and stands at the same level as later-stage investment (which quadrupled). This is mainly due to the limited activity in the past, but also the emergence of start-ups, which are only on the verge of reaching the scale-up stage. Global venture capital investment has increased to an all-time high in 2021, reaching EUR 57 million (+28% as compared to 2020). Nevertheless, 60% of early and later stage investment over 2016-2021 benefited only three companies in the United States (Dandelion Energy, Stone Mountain Technologies and Thermolift) ([90]).

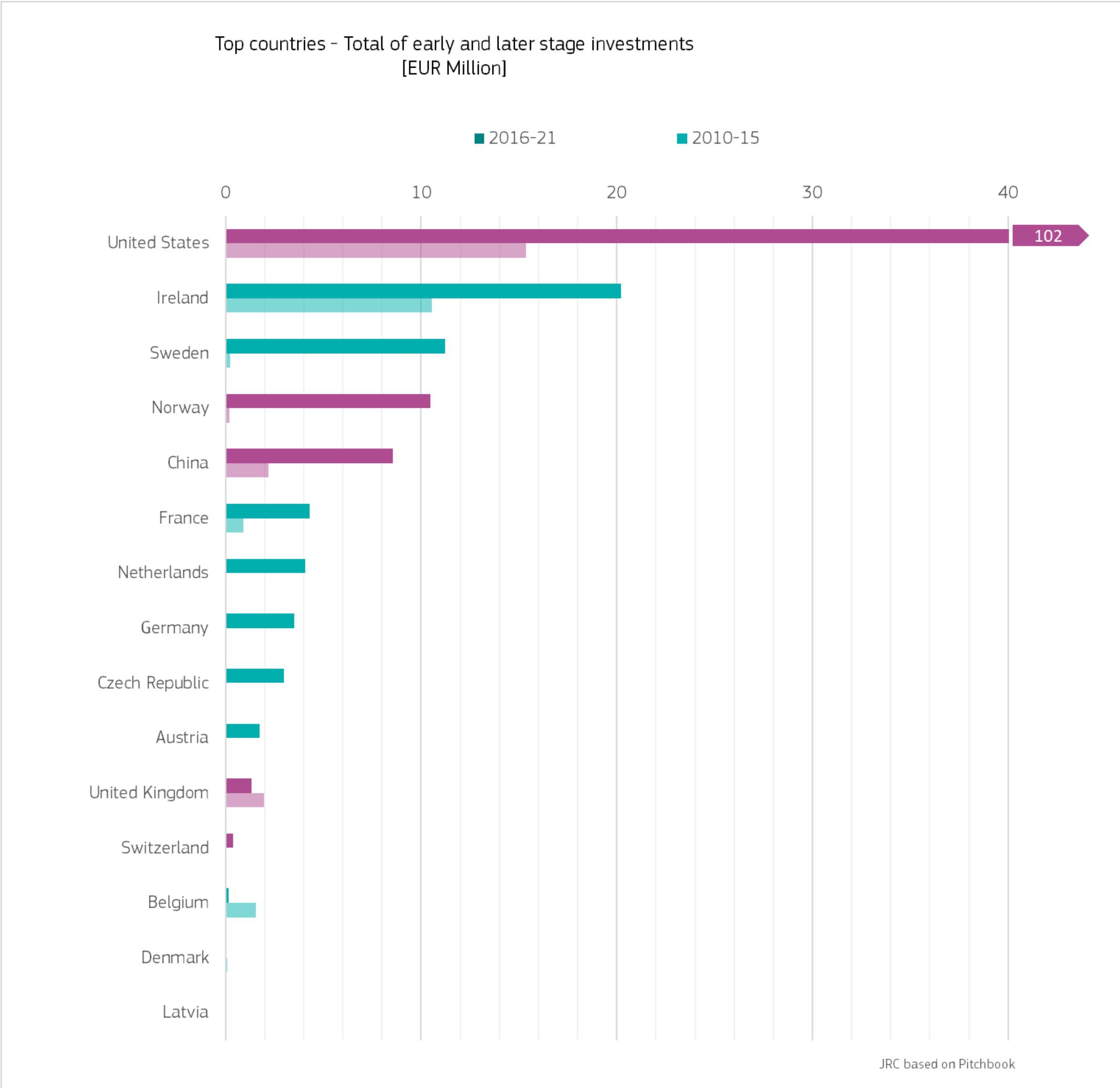
The EU has not kept pace with the rest of the world and only accounts for 10% of early-stage investment over the 2016-21 period, amounting to EUR 9 million, despite an increase in 2021. The US and Norway are in the lead, followed by Ireland and the Netherlands in the early stages. By contrast, the EU is doing better in the later stages, accounting for 45% of investment. However, EU later stage investment displays a sharp drop-off since 2017. The US is again in the lead, followed by Ireland and Sweden. Examples of EU companies receiving venture capital investment include Exergyn (IE), Heat transformers (NL), Easyserv (SE) and TECCONTROL (FR) ([91]). **Figure 36** displays countries ranked by total early and later stage investment in 2016-2021 compared to 2010-2015.

([89]) This data, however, is, limited to IEA Members and their disclosures, therefore, should be interpreted with caution.

([90]) See https://dandelionenergy.com/ (ground-source heat pumps), https://stonemountaintechnologies.com/ (gas-fired heat pumps) and https://thermoliftsolutions.com/ (heat pumps using helium as refrigerant.

([91]) See www.exergyn.com/ (shape memory alloys), www.easyserv.se/ (digitalisation) and www.teccontrol.fr/ (hot water, and solutions provider).

Figure 36. Total of early and later stage investment [EUR] million (2010-15 and 2016-21)([92])

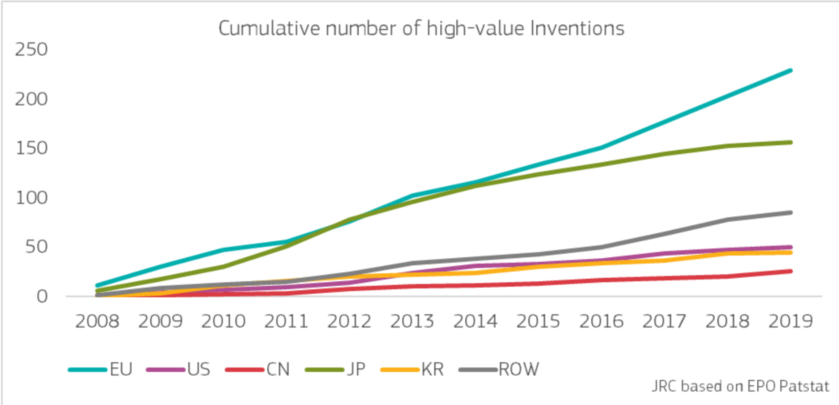


Source: JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard (CIndECS) (Draft, 2023)

EU patenting activity remains strong and keeps growing, with 45% of the world's high-value inventions (2016-2019), as seen in **Figure 37**. At country level, Germany has the biggest portfolio of high-value patent filings, followed by Japan and Türkiye. Also, France, Italy and Sweden feature in the top 10. Arcelik (Türkiye) leads among the companies, followed by Mitsubishi (Japan) and Bosch Siemens (Germany). With five companies among the top 10, the EU is well represented among the patenting corporates.

Figure 37: Cumulative high-value inventions since 2008 for the major economies ([93])

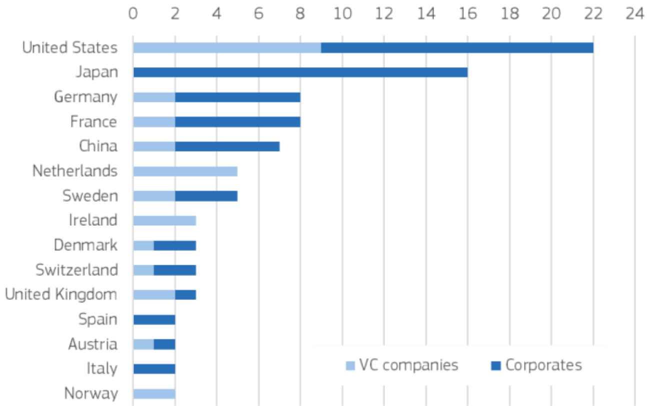
([92]) The darker shade of purple and teal respectively refer to the latest period 2016-21 and the lighter shade refer to the earlier period 2010-15.
([93]) Major economies included in the figure: EU (European Union), US (the United States), CN (China), JP (Japan), KR (Republic of Korea), and ROW (rest of the world).



Source: JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard (CIndECS) (Draft, 2023)

As shown on **Figure 38**, the number of identified innovators is distributed across many countries. Together, the US (first) and Japan (second) host 38% of active companies. The US relies on a strong base of venture capital companies, while all innovators in Japan are corporations. The EU hosts 42% of identified innovators, and is in a strong position with a good balance between venture capital companies (45%) and corporate innovators (55%). The Netherlands hosts the largest number start-ups in the EU, while Germany and France host overall the biggest ecosystem of innovators in the EU.

Figure 38. Number of innovating companies by type (2016-2021)



Source: JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard (CIndECS) (Draft, 2023)

Innovation efforts are currently focused on smart and flexible features, better efficiency, wider ambient temperature range, higher temperature output, lower noise, reduced size, improved ease of installation, enhanced recyclability, and substitutions for certain materials, such as refrigerants to lower the environmental footprint (Lyons L. , et al., 2022). Efforts are also being made towards largescale heat pumps for industry and district solutions. Next-generation heat pumps need to operate efficiently in very cold temperatures, over a larger temperature range, and in buildings with lower insulation. This requires further research and development of certain components, such as compression technologies and system designs (IEA, 2022).

6.3 EU competitiveness

Heat pumps are steadily improving in cost-competitiveness and efficiency ([94]), which along with technological developments such as hybrid systems, digitalisation and integration with other energy technologies, is enabling a rollout of heat pumps to a larger share of buildings (Lyons L. , et al., 2022). Hybrid systems ([95]) are particularly popular in Italy and the Netherlands. The current energy crisis is changing a previously unfavourable price ratio between electricity and gas in favour of heat pumps. In addition, many countries have different support schemes to incentivise households to switch. Yet high up-front investment costs remain the main factor in deterring households. Several non-cost barriers, such as lack of information, split incentives for building owners and tenants, and building regulations, have also hampered wider adoption (IEA, 2022).

The European heat pump industry is well established and the leader in most heat pump segments, consisting of many SMEs and a few large manufacturers. None of the companies dominate the entire EU market. Some consolidation has taken place recently and it may be essential to exploit economies of scale and ensure competitiveness against Asian-Pacific air-conditioner giants that could potentially compete with lower costs. China and the US are implementing policies to support manufacturers to export (Lyons L. , et al., 2022), potentially eyeing the EU market. In this regard, the creation of standards and labels at European level, for example through Ecodesign, can help to ensure that European sustainability standards are met and that European producers are not put at a disadvantage.

Figure 39 shows that the EU scores highly on most innovation-related indicators. However, its relative performance is dropping slightly. EU public R&D investment is growing but this growth is slowing. The EU still holds a strong global position in high-value patenting and later stage investment, even with a slight drop of its share. The EU continues to host a high share of innovators headquartered in the EU, with five corporates among the top 10 patenting entities. EU-based start-ups have not attracted the same level of early-stage investment as their non-EU counterparts, which is worrying as venture capital investment is growing globally. Thus, the EU has a strong foothold in innovation but efforts are needed to maintain this edge. Future market opportunities also lie in digitalisation and system integration with smart grids and building management systems.

With the booming market, EU turnover and employment are increasing. EU production still exhibits strong growth, signalling the industry's capacity to meet growing demand. Demand is expected to grow even more strongly in the years to come, intensifying competition with non-EU producers who enter the market. Chinese producers are already taking up a slice of the EU market, as evidenced by the transformation of the trade surplus into a growing deficit since 2020. US manufacturers supported by the Inflation Reduction Act may also be eyeing the European market. Strong EU performance in innovation should help the industry to tap this potential, but it must better deploy economies of scale if it is to overcome cost-cutting competition from outside the EU. In addition, the industry needs long-term supportive regulations, including the removal of any potential barriers in the Single Market, to promote investment in EU manufacturing lines, and avoid the fate of solar PV which lost its European industrial base.

([94]) For more information on costs, see Lyons et al. (2022).
([95]) Hybrid systems have an advantage that they can be deployed in buildings that are less well insulated. At the same time, they may result in higher emission by extending the use of gas boilers (used as a back-up) for longer, delaying also deeper renovations. For more, see Lyons et al. (2022).

Figure 39. Scoreboard for heat pumps

Scoreboard	Heat Pumps	EU performance in the reference period			Change from 2021 assessment
Public R&D	●	8%	2016-2020	EU CAGR	↓
Early Stage	◐	10%	2016-2021	EU share of global total value	↓
Later Stage	●	45%	2016-2021	EU share of global total value	↓
Patents	●	45%	2016-2019	EU share of global total HVI	↓
Companies	●	42%	2016-2021	EU share of innovating companies	↓
Employment	●	7%	2016-2020	EU CAGR	→
Production	●	9%	2016-2021	EU CAGR	↑
Turnover	●	8%	2016-2020	EU CAGR	→
Imports & Exports	●	37%	2019-2021	EU share of global exports	↓
Trade Balance	○	Low	2016-2021	EU trade balance trend	→

Legend	● High	◐ Medium	○ Low
Summary of criteria			
Public R&D	>2%	0< and <2%	<0%
Early Stage	>18%	8%< and <18%	<8%
Later Stage	>18%	8%< and <18%	<8%
Patents	>25%	15%< and <25%	<15%
Companies	>25%	15%< and <25%	<15%
Employment	>1%	0%< and <1%	<0%
Production	>3%	0%< and <3%	<0%
Turnover	>2%	0%< and <2%	<0%
Imports & Exports	>25%	15%< and <25%	<15%
Trade Balance	positive / improving		negative / deteriorating

Change from 2021 assessment	
↓	2 pp. lower
→	within +/- 2 pp
↑	2 pp. higher

Source: JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard (CIndECS) (Draft, 2023)

In March 2023, the European Commission launched the Net Zero Industry Act ([96]) to strengthen the resilience and competitiveness of net-zero technologies manufacturing in the EU, where one of the key technologies are heat pumps. One of the objectives is to make sure the supply can meet the rapid growing demand, by measures like fostering innovation and R&D, enhancing skills and by removing administrative barriers.

([96]) https://single-market-economy.ec.europa.eu/publications/net-zero-industry-act_en

7 Conclusions

Replacing fossil fuel boilers with heat pumps not only offers significant climate benefits, but it also contributes to improving the energy security of the EU. Replacing 30 million oil and gas boilers by 2030 (approximately 35% of them) would result in a 36% reduction of the gas and oil consumption in these buildings and a 28% reduction of their CO_2 emissions ([97]). The associated CO_2 emissions reductions will grow with the decarbonisation of the power system. In countries with a low-carbon power mix, such as Sweden, Finland, France and Luxembourg the operation of heat pumps is close to carbon-neutral.

Heat pumps work more efficiently when deployed in well- thermal insulated buildings, although they can often function reasonably well in less efficient buildings, albeit at a reduced efficiency level ([98]). The majority of buildings within the EU are old and rather inefficient. Based on our assumptions, around 60% of buildings currently heated by gas or oil boilers should undergo upgrades to ensure high-efficiency operation of the heat pumps. Ideally, these would be deep renovations. However, a partial renovation and/or adjustments to the distributional heating system would also enhance their efficiency. Furthermore, high-temperature heat pumps or hybrid heat pumps can be a transitional solution for buildings with lower performance levels.

Until 2022, annual installations of gas boilers exceeded those of heat pumps. Adding new gas boilers to the existing stock makes the challenge ever greater and locks in investment and the dependency on gas for the foreseeable future. Just replacing 30 million gas and oil boilers with heat pumps by 2030 will require an increased exchange rate of fossil fuel boilers of up to 5.5%, assuming that all boilers are replaced with heat pumps. It is essential to ramp up the deployment of heat pumps and the exchange of old boilers fast, in order not to face an unfeasible challenge later on. This also assumes that the number of new fossil fuel boilers in the system is minimised.

The heat pump value chain faces a considerable challenge. Installing 30 million heat pumps by 2030 means more than a doubling of the yearly deployment rate of heat pumps compared to 2020 ([99]). Last year's sales data indicated a 40% increase in heat pump sales, which means we are on track to meet the target. However, the deployment rate of heat pumps in the existing building stock have not been sufficient. Although heat pumps have recently become more popular in older buildings, a large share of installations have been in new constructions. Heat pumps offer a cost-effective alternative to fossil fuelled boilers in the majority of existing buildings. Furthermore, EU has set out to renovate a large share of the existing building stock which further improves the cost-effectiveness of heat pumps in these buildings.

Replacing a fossil fuel boiler with a heat pump leads to a significant decrease in utility expenses for the majority of households. According to the analysis, the annual energy cost savings can vary between 20% and 60%. However, the actual savings depend on factors such as gas and electricity prices, as well as the level of energy savings achieved. For less efficient buildings, the payback times are longer, as these buildings need renovation; subsidies are often needed to stimulate the investment decision. Furthermore, the higher taxes and fees affecting electricity more than gas in most markets, as well as a limited internalisation of carbon costs for fossil-fuelled heat sources, have a negative influence on the cost-effectiveness of heat pumps.

The price ratio between electricity and gas remains a challenge. The ratio plays a crucial role in determining the competitiveness of heat pump operating costs. When the price ratio exceeds the seasonal performance factor (SPF) of heat pumps, the fuel costs of heat pumps become higher than that of gas boilers. Assuming a SPF of three, operating a heat pump remains cost-effective as long as the price of electricity does not exceed three times the gas or oil price. In 2021, 19 Member States had an electricity-to-gas ratio exceeding three, whereas only six Member States had a ratio of three during the first half of 2023. Achieving a favourable and stable electricity/gas ratio would allow heat pumps to maintain their efficiency advantage and ensure their economic viability compared to fossil-fuelled heating systems.

The electrification of heating through heat pumps will influence the electricity market dynamics by increasing the supply requirements, if no countermeasures in terms of demand response are taken. The analysis shows that, for the whole EU, with 52.1 million installed heat pumps by 2030, the heat pumps electricity demand

([97]) Considering the current CO_2 emission factors for electricity of all EU Member States.
([98]) Contingent on the gas and electricity prices, it is, in many cases, still cost-effective.
([99]) Commission's REpoweEU plan of doubling of the rate of deployment of heat pumps https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131

reaches up to 11% ([100]) of the total grid demand during a cold winter's day. If a large share of heat pumps are using setback temperature during night-time, the peak demand risks being some percentage points higher. The analysis indicates that the additional strain on power grids due to increased demand will be relatively moderate. However, the main concern is that this increased demand coincides with heightened electricity usage in other sectors, such as transportation and industry. Additionally, in countries where direct electric radiators are commonly used, if these are also replaced with heat pumps, the overall impact on the electricity grid will be even lower.

Demand response flexibility strategies can alleviate a considerable portion of the stress the heat pump deployment will cause on the power grids. The electric shifting potential of heat pumps ranges between 0.18 and 10.68 kWh per heat pump unit and load-shift cycle, according to one study. The flexibility potential depends on the insulation of the building, the season (the potential is higher during winter when more electricity is used), and the flexibility strategy used. When extrapolated to a pool of one million heat pumps, the potential exists to shift a substantial amount of electricity demand, ranging from 4 to 14 GW per hour (Gunther, et al., 2020). The EU has seen a positive trend in the regulation and implementation of demand response but there is still untapped potential to explore.

European companies are still dominating the EU market for heat pumps. Notably, the most substantial surge in imported heat pumps occurred in 2022, with China emerging as the leading contributor. Other large markets, including China and the United States, are actively pursuing strategies to scale up their heat pump deployment as well, which is likely to result in increased competition. EU companies still maintain a strong position, investing in innovation and in adopting new technologies, such as natural refrigerants. One target of the EU Heat Pump Action Plan could be to support the industry to continue to invest in R&D, to make sure that EU companies hold their global frontrunner position.

The analysis looked closer at several challenges that could influence the scale-up, including supply chain shortages, the lack of skilled installers, the high upfront costs for households, and the phase out of F-gases used as refrigerants in conventional heat pumps.

- The accelerated development of heat pumps necessitates a greater number of skilled professionals across the whole value chain. Naturally, there is a need for more installers with expertise in heat pumps. There is also a necessity for energy experts who can provide households with the right guidance for homeowners, offering insights on heat pump selection, sizing, integration into existing systems, and possible combination with other energy upgrades. While installers of boilers possess certain competences relevant to heat pump installation, they require retraining to cover the requirements unique to heat pumps. This includes acquiring knowledge about sizing the piping system in buildings but also the handling of the refrigerants used in the system. It should be noted that the number of installers and their skill levels differ substantially between Member States.
- The high upfront cost is a genuine barrier. The initial investment required for an air-water heat pump typically exceeds EUR 10 000, considering the expenses associated with equipment and installation. In most cases, the upfront cost of an air-water heat pump can be more than double the cost of installing a new gas boiler. Additionally, many buildings will require modifications to their heating distribution system and investment in energy renovations, further increasing the overall cost of installing an air-water heat pump. Air-air heat pumps offer a significantly lower upfront cost compared to air-water heat pumps. However, they are typically not employed to heat an entire building. Nevertheless, they present an excellent opportunity to reduce the energy consumption of existing heating systems like gas boilers or direct electric radiators. By utilising air-air heat pumps in conjunction with these systems, significant cost savings can be achieved. Financial support schemes ought to lower the barrier to invest in heat pumps and favour the most efficient systems for the specific buildings, taking into account cost, efficiency and climate impact.
- The phase-out of F-gases could be challenging for industry in the short term. While such heat pumps and their components are available today, further upscaling and the creation of

([100]) We made a simplified assumption that all houses with heat pumps would increase the temperature of the thermostat at the same time in the morning. Hence, this peak electricity demand might be smoothened in reality. Moreover, for houses that are less well-isolated, it is recommended to keep more or less constant temperatures throughout both night and day.

production capacities are needed. 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. In addition, such action avoids the creation of large banks of equipment using refrigerants with high GWP, saving significant amounts of direct emissions for several decades. Replacing these refrigerants quickly is therefore an opportunity for industry to move to truly green technologies. Simplifying and streamlining administrative requirements to the use of natural refrigerants is needed to support the industry in this transition.

- There are currently no major shortages or import dependencies for components. The global shortage of semiconductors poses a barrier in the short term. However, those commonly used in heat pumps are not highly specialised or advanced, which means they can sometimes be sourced or repurposed from adjacent manufacturing sectors.
- Heat pumps and energy efficiency in buildings are long-term solutions to energy poverty, as the higher efficiencies make utility bills more affordable. Almost one third of Europeans are unable to face unexpected expenses. Thus, the high upfront cost for heat pumps risks excluding vulnerable households from the clean energy transition. Special support should be aimed at these groups to make sure that heat pumps are successfully rolled out across society.

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List of abbreviations and definitions

EPBD	Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings OJ L 153, 18.6.2010, p. 13–35
EED	Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC, OJ L 315, 14.11.2012, p. 1–56
RED II	Directive (EU) 2018/2001of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources, OJ L 328, 21.12.2018, p. 82–209
COP	Coefficient of Performance
SCOP	Seasonal Coefficient of Performance
BRP	Building Renovation Passport
EU27	27 European Union countries

AT	Austria
BE	Belgium
BG	Bulgaria
HR	Croatia
CY	Cyprus
CZ	Czechia
DK	Denmark
EE	Estonia
FI	Finland
FR	France
DE	Germany
GR	Greece
HU	Hungary
IE	Ireland
IT	Italy
LV	Latvia
LT	Lithuania
LU	Luxembourg
MT	Malta
NL	Netherlands
PL	Poland

PT	Portugal
RO	Romania
SK	Slovakia
SI	Slovenia
ES	Spain
SE	Sweden

Energy need for heating or cooling heat to be delivered to, or extracted from, a conditioned space to maintain the intended temperature conditions during a given period of time

NOTE 1 The energy need is calculated and cannot easily be measured.

NOTE 2 The energy need can include additional heat transfer resulting from non-uniform temperature distribution and non-ideal temperature control, if they are taken into account by increasing (decreasing) the effective temperature for heating (cooling) and not included in the heat transfer due to the heating (cooling) system (ISO , 2008).

Energy use for space heating or cooling energy input to the heating or cooling system to satisfy the energy need for heating or cooling, respectively

NOTE If the technical building system serves several purposes (e.g. heating and domestic hot water), it can be difficult to split the energy use into that used for each purpose. It can be indicated as a combined quantity (e.g. energy use for space heating and domestic hot water) (ISO , 2008).

Seasonal coefficient of performance (SCOP) or seasonal primary energy ratio (SPER) is the overall coefficient of performance of a heat pump space heater or heat pump combination heater using electricity or the overall primary energy ratio of a heat pump space heater or heat pump combination heater using fuels, representative of the designated heating season, calculated as the reference annual heating demand divided by the annual energy consumption (Regulation 813/2013).

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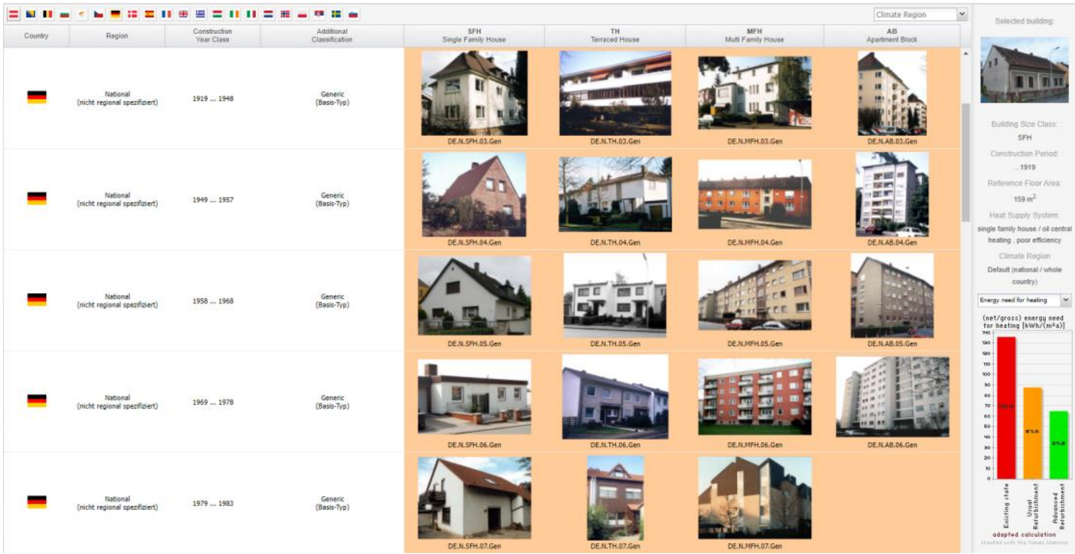
Annexes

Annex 1. Methodology

The EBEM building model is a bottom-up model able to analyse current and future energy trends based on a disaggregated building stock of EU27 (table below shows the workflow of the model). The model comprises several databases (building stock, climate, techno-economics of energy systems and renovation options, policy measures) and calculation modules (yearly, hourly energy demand for heating, cooling, DHW, costs calculation). The building stock is organised according to typical building typologies per country, and covers information on aspects such as single-family houses, multi-family houses, apartment buildings and year of construction, thermal insulation, and heat source. Building data have been gathered from public data sources, e.g., the H2020 project Hotmaps (Pezzutto, et al. 2019), the IEE project TABULA, the EU Building Stock Observatory (IWU 2016), JRC report (Nijs, Tarvydas, & Toleikyte, 2021), Study for DG ENER Mapping H&C (Fleiter, Steinbach and Ragwitz 2016). The model uses the climate data from JRC ERA NUTS, based on C3S ERA5 (hourly time resolution; NUTS0 geographical resolution) and solar irradiation from PVGIS ([101]).

The modelling of the future energy demand takes into account the development of the building stock, considering renovation rates, demolition rate and new constructions, as well as the energy demand savings achieved by thermal renovation and heating system change. The model is able to interact with the METIS model to analyse the impact of energy consumption trends (e.g. by increasing number of heat pumps) on the electricity and gas systems.

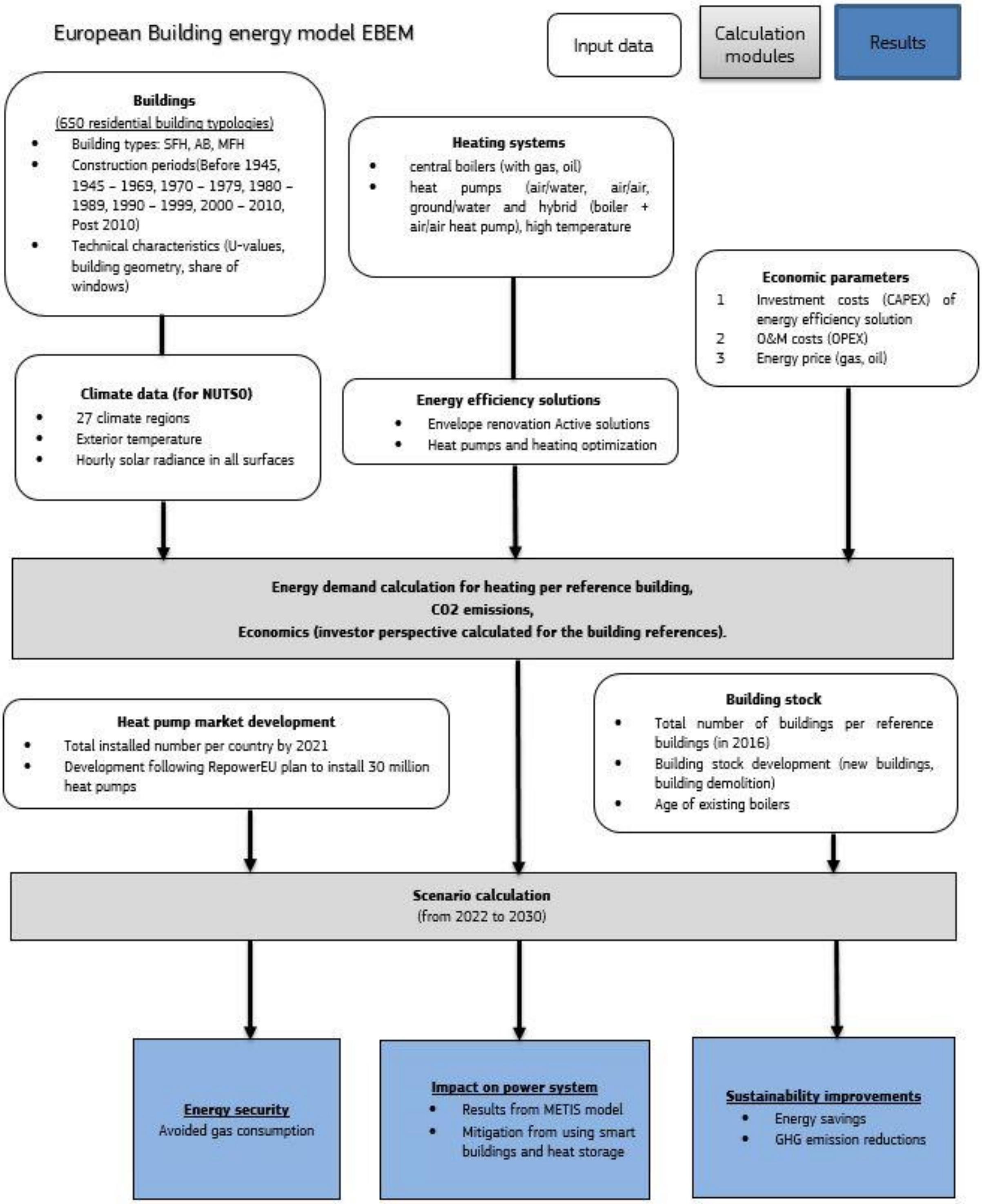
Figure 40. Extracted from the TABULA database



Source: (IWU 2016)

([101]) https://joint-research-centre.ec.europa.eu/pvgis-online-tool_en

Table 8. Workflow of the EBEM (European Building Energy Model)



Source: own illustration.

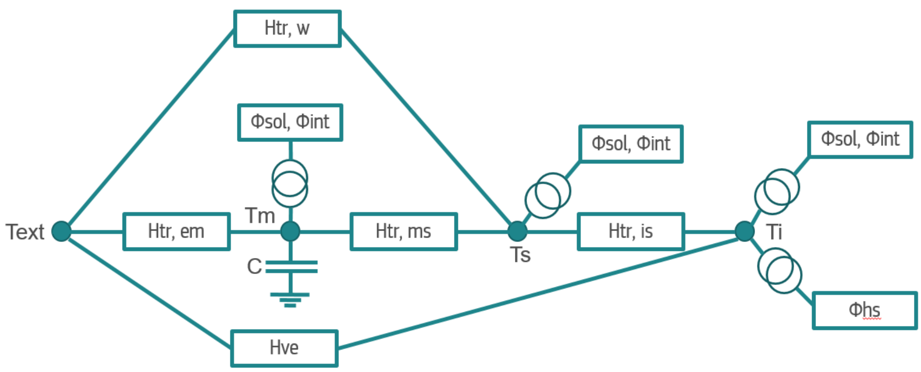
Energy needs calculation methodology

The EBEM model and its hourly energy package, is based on the EN ISO 13790 standard. The model creates an hourly time series for one year of energy needs and energy uses, also compares different heating systems such as: air/Water heat pump, air/air heat pump, boilers, geothermal heat pump, high temperature heat pump, hybrid or bivalent solutions, etc.

This model is a simplified version of the one of ISO 13790, which has been adapted to TABULA building information. Both models methodology describe them following an electrical diagram, in which the electric intensity can be the heat flow and the voltage the temperature. The Inertia of the building is a capacitor and the different kind of losses are electric resistance. The gains and the energy that comes from the heating system to maintain the internal conditions are similar to electric generators in this kind of schemes.

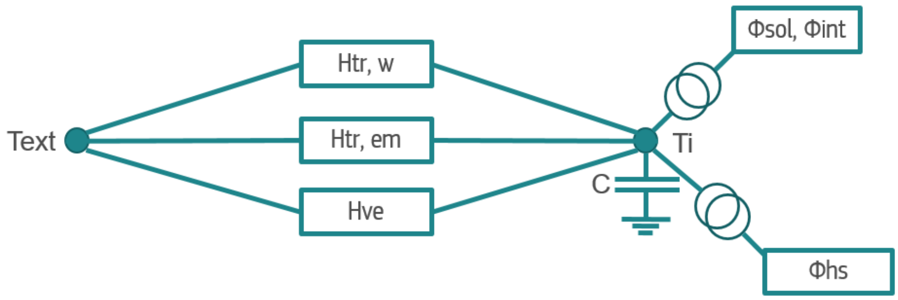
Figure 41, **Figure 42** presents the electric schemes. The main difference is that the model of ISO 13790 includes the temperature of the mass of the opaque elements of the envelope and the temperature of the interior surface of the envelope. For that reason, the transmission losses by the opaque elements of the envelope have two resistances. The EBEM model makes a simplification of that model because of the information available in the building database used, so that the transmission losses by the opaque elements are in one term and is assumed that the internal temperature is uniform inside the building.

Figure 41. Electrical scheme of the ISO 13790 energy model



Source: own illustration based on EN ISO 13790 standard.

Figure 42. Electrical Scheme of the JRC C7 Building Model.



Source: own illustration based on EN ISO 13790 standard.

System operation

The operation of the system includes two scenarios of assumptions about the hours where the system should be working, and the temperatures of the thermostat, which the systems has to reach.

In the first scenario, the hours when the system works are from 08.00 until 23.00. During these hours, the objective of the system is to provide enough energy to reach the internal conditions required, which are:

— 20 °C during 08:00h – 23:00h

— 17 °C during 00:00h – 08:00h. In this period, the objective is not to maintain 17°C, as the heat pump should be switched off. The system only starts working if the temperature during night is lower than 17°C. This action has been implemented in order not to have a hard start of the heat pump in the morning.

The heating system will have to supply the difference between losses and gains, and provide enough energy to reach the level of temperature required by the set point of the thermostat. This delivered energy to increase the temperature of the building becomes much more important during the mornings, when the system starts working after all night switched off.

In these moments of the day, the temperature is between 17°C and 18°C and the set point of the thermostat is 20°C, so that the heating system will have to provide with the difference between gains and losses plus the energy needed to reach 20°C. According to the capacity of the system, this procedure can take 2-3 hrs as an average.

Once the building reaches the 20°C, the heating system only have to supply the difference between gains and losses, in order to maintain the internal conditions.

The second scenario takes into account the assumption of having the heating system working 24h during the heating season. This means that the heating system will try to provide all the energy that is needed to maintain 20 °C in the building selected during all the day. Furthermore, the level of temperature does not need to be increased, for that reason the heating system only has to provide enough energy to equalize the thermal losses, which means that most of the time will be working at part load ration conditions without big peaks in the morning.

It is worth mentioning that these scenarios are based on own assumptions. The real behaviour of the heating systems depends on the final user, and for residential sector this is a matter very challenging to predict.

Systems characteristics

The definition of the systems is based on two main characteristics: Rated capacity and performance curves. All this characteristics can allow predicting the energy use of different systems, which means to predict the gas consumption of boilers and electricity consumption of heat pumps.

Rated Capacity

The rated capacity of the system is obtained by calculating the thermal losses at 99% percentile of exterior temperature. That will be the rated capacity for systems like boilers or geothermal heat pumps, which capacity do not vary in function of the exterior conditions. However, when it comes to air/source heat pumps, it is different. For example, if the temperature at which the capacity is calculated is -10°C and the result is 7kW, which is not the rated capacity of an air source heat pump. This capacity is the capacity that the air source heat pump has to provide at those conditions, as the capacity of the heat pump depends on the exterior temperature. The rated capacity of an air/source heat pump should be expressed at an exterior temperature of 7°C and 35°C of water supply temperature. Furthermore, once the capacity is calculated, this capacity is corrected by the use of a coefficient, which comes from the capacity curve.

Performance curves

The elements which allow to calculate the performance of the heating system in function of several conditions are the performance curves. According to the kind of system, the inputs of the performance curves can change. The curves are described as follows:

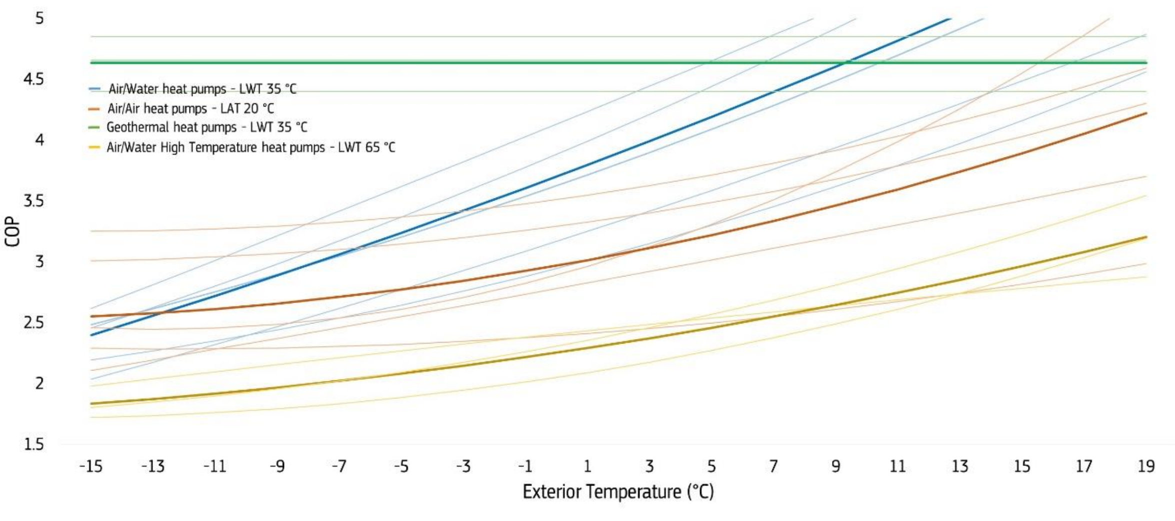
— COPfText: This is a biquadratic curve in function of the exterior temperature and the water supply temperature. This curve is used in air source heat pumps, like air/air, air/water, or high temperature air/ water heat pump. The final output of the curve is the COP of the heat pump. Figure below presents all the curves are classified by technology with the average curve of each technology highlighted. A fact worth noting is that geothermal technology maintains steady, as its performance does not depend on the exterior conditions, which performance depends on the temperature of the brine/water loop, which is considered constant in this study. Other important matter is the difference of COP between air/water heat pumps and high temperature air/water heat pumps. As the high temperature ones need to work at a high level of condensation pressure, the performance drops as the compressor needs more energy to circulate the refrigerant in the loop. Furthermore, the COP can vary if the water flow temperature varies as well. But a limitation of the energy simulation model is to consider the water temperature production constant during all the heating season. This approach means that the assumption here is that the system works with a constant water flow and temperature, so the only variable here is the return temperature, the lower the load the bigger the return flow temperature. Another approach could be to vary the flow and maintain the temperature drop constant.

— CAPfText (Capacity in function of exterior temperature): This is the same kind of curve as the one before. The only difference is that this curve represents the maximum capacity of the heat pump in function of the exterior temperature and water supply temperature.

— RendfPLR (Performance in function of PLR (Part Load Ratio)): This curve represents the performance of a boiler in function of the capacity delivered in each moment. Is a polynomic curve of grade two and the only input is the part load ratio of the boiler, as the water supply temperature is fixed depending on the boiler. Part load ratio is the relation between the heating needs that the heating system is providing and the nominal capacity of the boiler. This effect is not taken into account in the curves of the heat pumps, due to the lack of information from different brands. Moreover, depending on the type of compressor it is not straight forward to generalize the same curves for an average heat pump.

Performance curves

Figure 43. COPfText curves



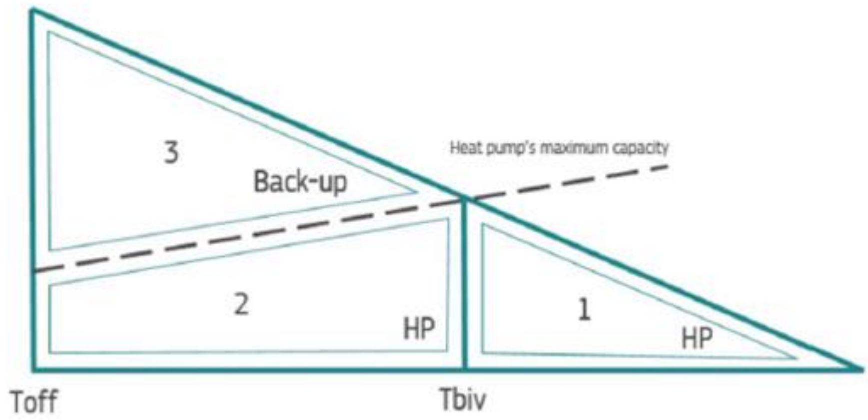
Source: own visualisation based on data provided by various manufacturers.

NL: LWT: leaving water temperature; LAT: leaving air temperature, COPfText: Coefficient of Performance in function of exterior temperature

Hybrid heat pump

In this analysis, we define a hybrid heat pump as a solution which combines an air/water heat pump and a condensing gas boiler. We assume that, the heat pump is the main system, and the boiler is used as a back-up. The activation sequence of both systems follows a rule in function of the exterior temperature (refer to Figure below). According to the exterior temperature, there could be only one or both systems working. In this study, there are two levels of temperature, which mark the behaviour of the systems: The bivalent temperature (Tbiv) and the cut off temperature (Toff).

Figure 44. System states of a hybrid heat pump

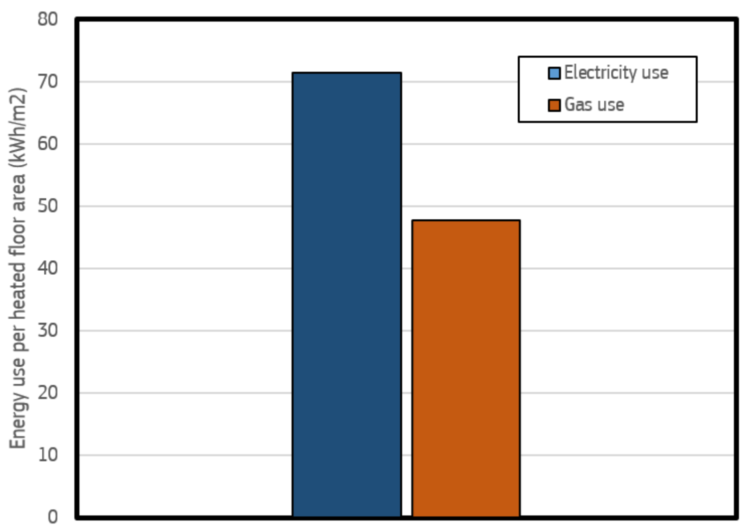


Source: own illustration.

Figure *45* shows three different states: For temperatures equal or bigger than the bivalent temperature (state 1), only the heat pump will work. If the temperature is below the bivalent temperature (State 2 and 3) the heat pump will start working unless the energy needs are bigger than its maximum capacity. If that phenomenon happens, the back-up will switch on. For temperatures below Toff, the heat pump will not be available and if that level of temperature is reached, only the back-up will work.

As an example, in figure below is represented the result of the energy balance of a building with a hybrid solution, which consists of an air/water heat pump as a main heating system and a gas boiler as back-up. The building selected is a single-family house from Germany, with a construction period between 1945 and 1969.

Figure 45. Energy use by electricity and gas.



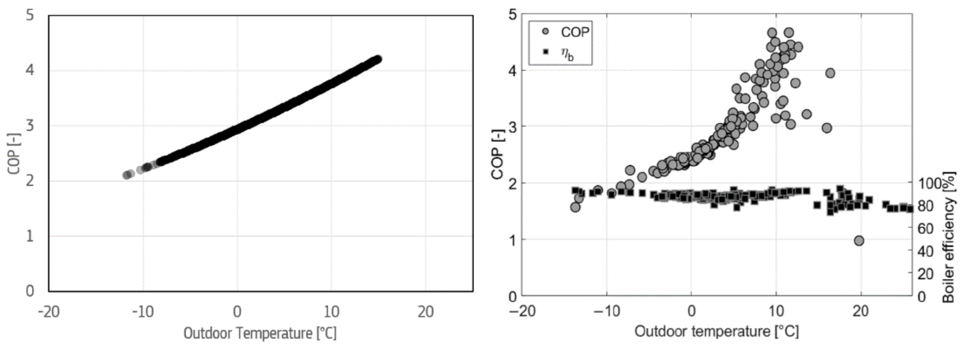
Source: own illustration.

Results and validation

The model works with building typologies that are in TABULA project. These buildings have been calculated and calibrated according to TABULA results. In terms of the total building stock, the total energy consumption in buildings per country has been validated with information from HOTMAPS and Eurostat.

In terms of systems modelled, the heat pump modelling has been compared with the work done by Neubert et al, 2022. In that work, the heating facility of a building from Germany was analysed. That facility was a hybrid solution composed by a heat pump and a gas boiler. In order to develop the comparison, a similar building from Germany was selected from the database used in the current study. **Figure *46*** shows that the results in terms of efficiency in the current study and in Neubert et al, 2022 study, have the same order of magnitude. It should be noted that the results that have to be compared are the ones related to the heat pump, which are the grey ones in the right graph (Neubert et al, 2022) and the results in the left graph (Current study). Something to highlight from the results is that both curves have a COP of 2 when the outdoor temperature is −10 °C, which is an evidence that the system still efficient at very low temperatures. Other comparison that is worth mentioning is the linear tendency of the left graph and the exponential tendence of the right graph. This is due to the right graph is a result of changing the water supply temperature (The bigger the outdoor temperature, the lower the water supply temperature) and then the COP of the heat pump increase much more when the exterior temperature increase. On the other hand, the left graph maintains the water supply temperature production constant, for that reason the approach is more linear. Nevertheless, both results have the same order of magnitude, which means that the curve calculated shows results in the order of magnitude of the literature.

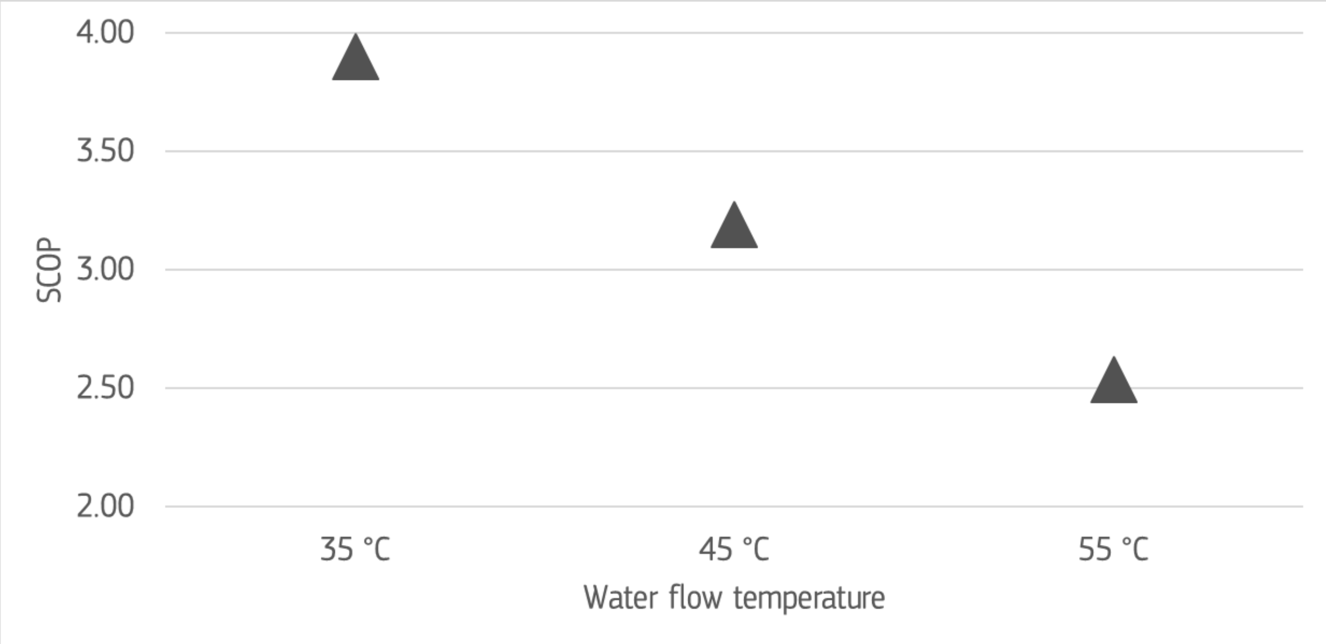
Figure 46. Air/Water heat pump performance curve from the current study (left) and Air/Water heat pump performance curve from Neubert et al, 2022 (right)



Source: own calculation (left) and Neubert et al, 2022 (right)

Figure 47 shows a comparison of the Seasonal Performance Factor (SPF), which can be named also Seasonal Coefficient of Performance (SCOP). The SCOP has been calculated by the use of the performance curves of the air/water heat pump modelled in the study. It represents the relation between the total heating provided and all the electricity consumed by the heat pump during all the heating season. It has been calculated for different water supply temperatures (35 °C, 45°C and 55°C). Figure below shows the results for a selected reference building which is a German single family house built in the 70s (partially renovated). These results illustrate the performance of the heat pump affected by the water supply temperature. According to the results, the SCOP can be reduced by 37% if the water supply temperature is 55°C rather than 35°C.

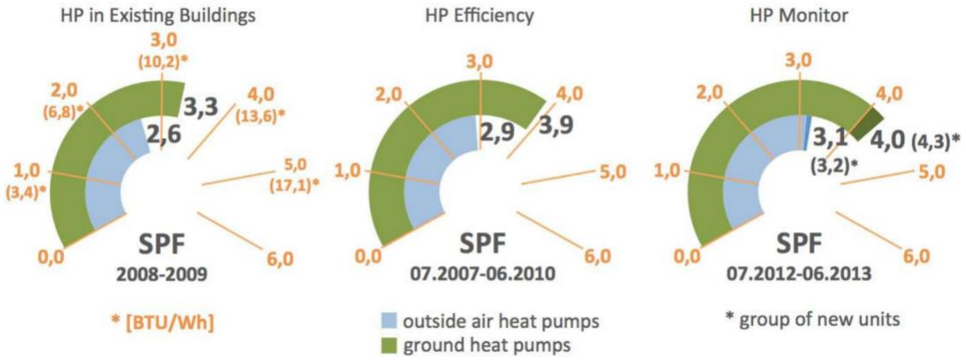
Figure 47. Comparison of the Seasonal Performance Factor for different water flow temperatures



Source: own calculation.

The results have been compared with the work by Miara et al, 2014, in which the SPF of heat pumps installed in Germany was measured. It is worth highlighting that the results of SPF of the our study are in the same order of magnitude. The output of that study is shown in figure below.

Figure 48. SPF for different houses



Source: Miara et al, 2014

Annex 2. National policies

Several Member States have implemented targets, strategies, and measures to accelerate the development of heat pumps in order to meet their climate targets and achieve energy independence. The implemented actions include heat pump targets, phase out of fossil fuel boilers, financial programmes, energy efficiency standards, building codes, awareness campaigns and investments in research and development.

Most Member States offer financial incentives to encourage homeowners or businesses to install heat pumps. These incentives typically comprise of tax credits or grants, with amount contingent on the previous heating system (e.g. a larger subsidy if replacing an inefficient oil boiler), CO_2 savings or heat pump capacity.

— The French MaPrimeRénov programme provides financial assistance to homeowners and landlords who want to make energy upgrades to their building. The objective is to reduce energy consumption and greenhouse gas emissions in the residential sector, and to promote the use of renewable energy sources for heating and cooling. Higher financial support is eligible for deep renovations and zero-carbon buildings. The available support for a heat pump depends on the income of the family, location of the building and type of heat pump ([102]).

— The German KfW programme offers financial incentives and low-interest loans to individuals, businesses, and public organizations to encourage the use of energy-efficient technologies, such as heat pumps, as a way to reduce energy consumption and greenhouse gas emissions. The subsidy covers between 25 and 40% of the installation cost, depending primarily on the heat pump type and the old technology being replaced ([103]).

— Similarly, the Czech Nová zelená úsporám supports investments in energy renovations of buildings. The main objective of the programme is to improve the state of the environment by reducing greenhouse gas emissions. Among other measures, the scheme covers up to 50% of the costs of a heat pump.

— Greece complements its heat pump subsidy with an additional 10% of the project costs in form of tax rebates for renewable heating installations.

Several countries have announced bans on fossil fuel boilers, as shown the map, including:

— Austria will be implementing a ban on the installation of oil and gas boilers in new buildings from 2023, and will also prohibit the use of oil and coal boilers in existing buildings.

— In Flanders (Belgium), the installation of oil boilers in new and renovated buildings is prohibited, and there will be a ban on connecting new buildings to the gas grid from 2025.

— In Brussels (Belgium), the use of fuel oil boilers will be prohibited from 2025.

— Denmark has already banned the installation of oil and gas boilers in new buildings since 2013, and is currently carrying out a program to phase out fossil boilers in existing buildings.

— France has implemented a ban on oil boilers in all buildings since 2022, and will ban gas boilers in new buildings from 2023.

— Germany plans to ban the installation of oil and coal boilers from 2026, and will require newly installed heating systems in new and existing buildings to operate with at least 65 percent renewable energy from 2024.

— In Ireland, there is a plan to ban the installation of new oil and gas boilers in all buildings from 2023 for new buildings, and from 2025 for existing buildings.

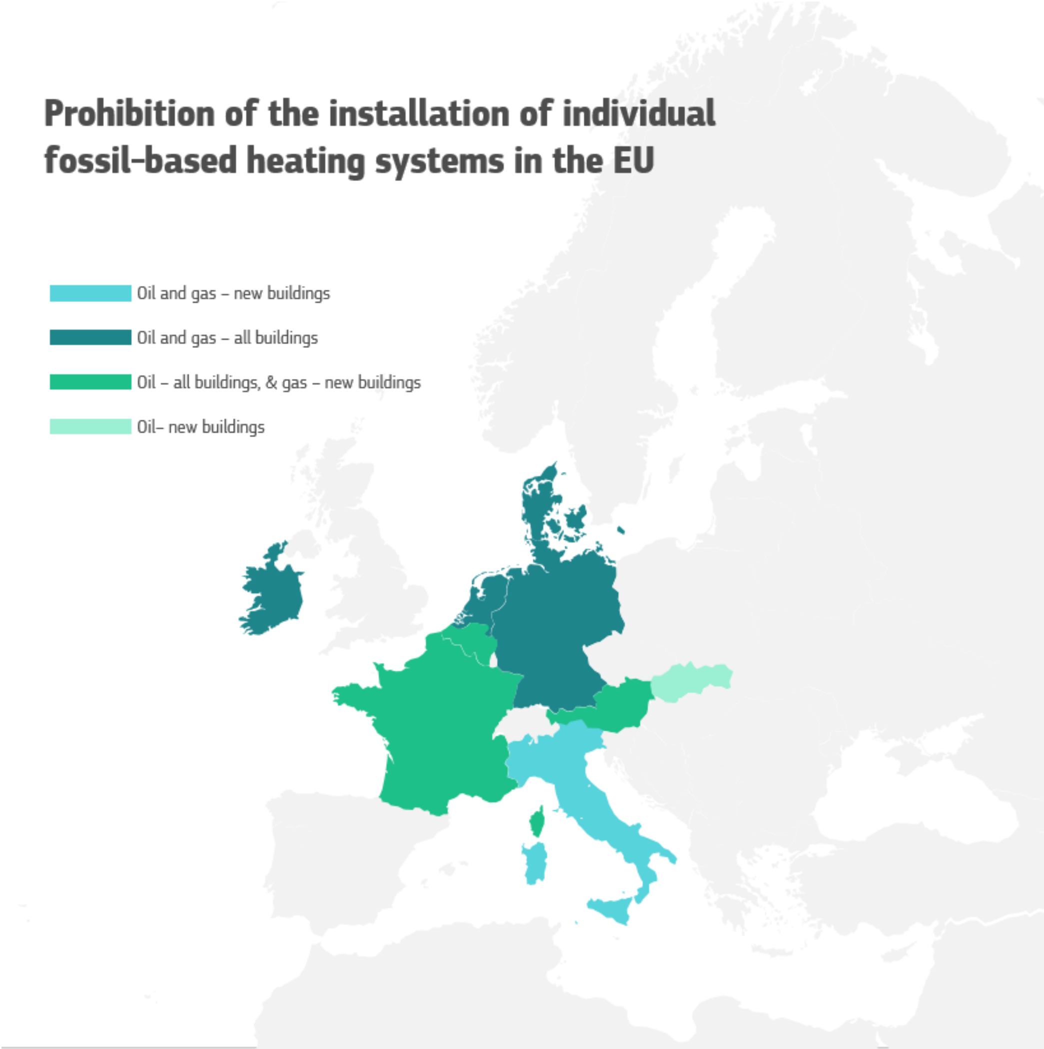
— The Netherlands has banned the connection of new buildings to the gas grid since 2018.

— Slovakia plans to ban the installation of new fuel and oil boilers from 2023.

([102]) https://www.ecologie.gouv.fr/sites/default/files/19164_maPrimeRenov_DP_Janvier%202021.pdf

([103])https://www.bafa.de/DE/Energie/Effiziente_Gebaeude/Foerderprogramm_im_Ueberblick/foerderprogramm_im_ueberblick_node.html;jsessionid=A80EBEFC400FCF3E1D5FE11DE6A12C0E.1_cid381

Figure 49. Prohibition of the installation of individual fossil-based heating systems



Source: own illustration based on EHPA 2022

In 2022, the European Commission announced an increase in its energy efficiency target for 2030, from 9% to 13%, as part of its REPowerEU proposal to end Russian fossil fuel imports. One aspect of this plan involves banning the sale of gas boilers by 2029. Several Member States have already banned gas and oil boilers in new constructions, which indirectly increases the demand for heat pumps. Denmark banned the installation of oil-fired boilers and natural gas heating in new buildings already in 2013, while several countries and regions have Set A date prior to the EU-wide ban in 2029.

The incorporation of renewable heating technologies, such as heat pumps, in buildings can be mandated or promoted through building regulations and certifications, such as the nearly zero-energy building definitions, and, more recently, zero emission buildings (D'Agostino, Tsemekidi Tzeiranaki, Zangheri, & Bertoldi, 2021) (Maduta, Melica, D'Agostino, & Bertoldi, 2022). The Energy Performance of Buildings Directive sets energy efficiency standards for new and existing buildings undergoing major renovations, including requirements for the use of energy efficient heating and cooling systems, which in most Member States incorporates heat pumps. In the Netherlands, they have implemented a *net zero energy building* standard with a related certification (i.e. NOM Keur), support by financial incentives. Heat pumps, in conjunction with solar power and thermal insulation, typically play a key role in achieving this high performance level and make it possible to detach the buildings from the gas grid ([104]) (see also (D'Agostino D. , Parker, Melià, & Dotelli, 2022) (D'Agostino D. , Parker, Epifani, Crawley, & Lawrie, 2022).

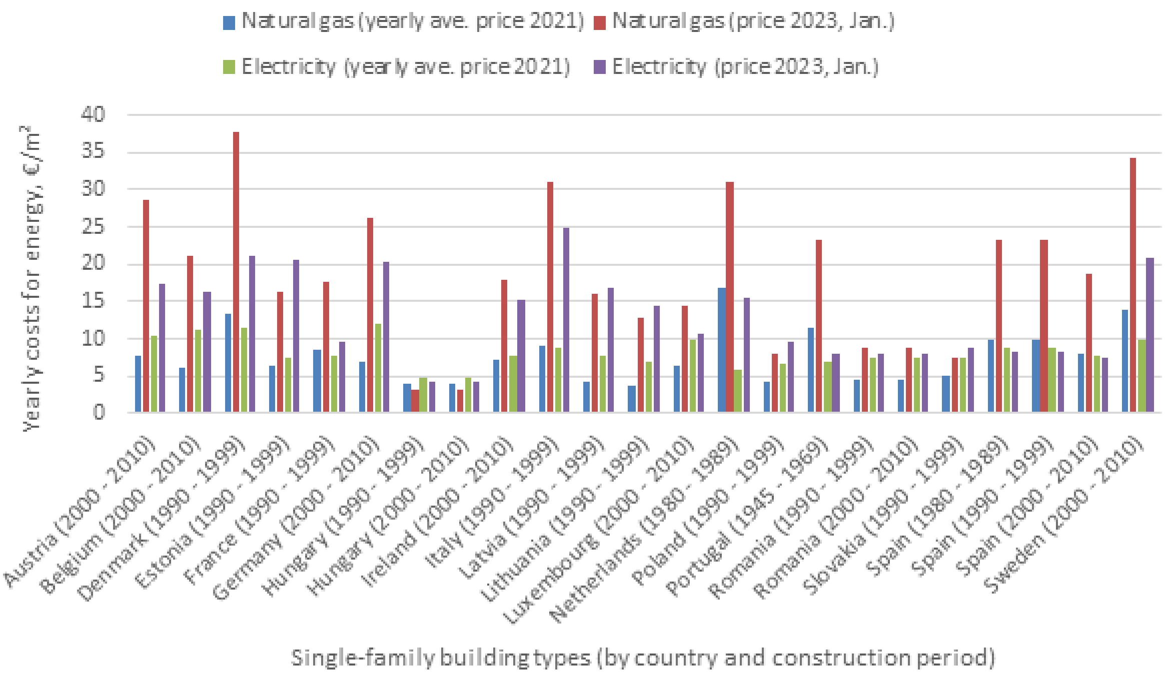
The low awareness of the suitability of heat pumps for homes continues to hinder the installation of heat pumps. Often, homeowners simply replace their old heating system with a similar one, rather than considering other options such as a heat pump. Some countries have implemented educational campaigns to increase awareness of the benefits of heat pumps and provide guidance on proper installation and maintenance.

Several countries have introduced advisory instrument to assist homeowners with technical guidance and support. One example is the building renovation passport, which is an individual renovation roadmap, setting out an optimal renovation pathway to decarbonise the building. The instrument recommends an optimal sequence of measures to ensure the appropriate actions are taken at the right time. The forward-looking instrument makes it possible to decide when its best to install a heat pump and which capacity is optimal for the current and future status of the building ([105]). The instrument already exist in a few countries (e.g. Belgium, France and Germany) and the European Commission proposed recently that it should be available in all Member States.

Annex 3. Other results and inputs

Figure 50 compares the yearly running costs for three single-family houses which use a gas boiler and switch to an air-water heat pump. **Figure 51** shows the financial viability of heat pumps across their lifetime (total early average costs from switching from gas to heat pump (including savings on energy and investment cost)).

Figure 50. Running costs for gas and electricity for single-family houses.

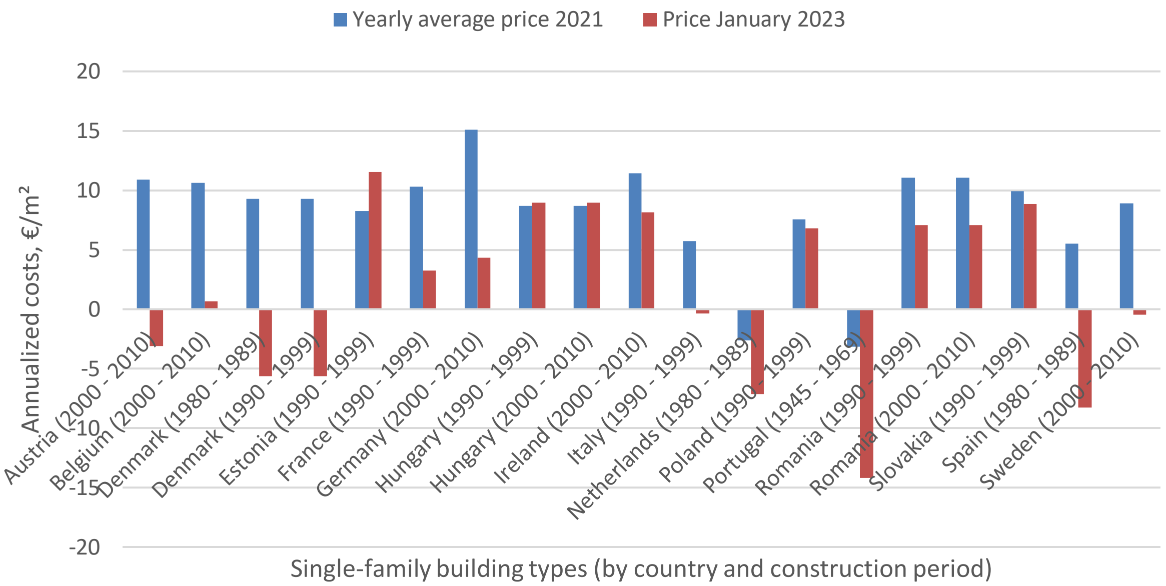


Source: own calculation.

([104]) https://www.rvo.nl/sites/default/files/Nul%20op%20de%20Meter_A4_Brochure.pdf

([105]) European Commission, Directorate-General for Energy, Volt, J., Fabbri, M., Zuhaib, S., et al., Technical study on the possible introduction of optional building renovation passports : final report, Wouters, P.(editor), Publications Office, 2020, https://data.europa.eu/doi/10.2833/760324

Figure 51. Total early average costs from switching from gas to heat pump (including savings on energy and investment cost)



Source: own calculation.

NL: Positive values indicate additional costs, while negative values represent cost savings. Negative values indicate that investing in a heat pump is financially viable.

Table 9. CO_2 emission factors

Country	**Gas (g CO_2/kWh)**	**Electricity** CO2-emission factors of electricity generation from the year 2020 **(g CO_2e/kWh)**	**Oil (g CO_2/kWh)**
Austria	202	78	264
Belgium	202	167	264
Bulgaria	202	362	264
Croatia	202	155	264
Cyprus	202	623	264
Czechia	202	390	264
Denmark	202	121	264
Estonia	202	621	264
Finland	202	64	264
France	202	60	264
Germany	202	314	264
Greece	202	454	264
Hungary	202	215	264
Ireland	202	281	264
Italy	202	216	264
Latvia	202	113	264
Lithuania	202	165	264

Luxembourg	202	61	264
Malta	202	378	264
Netherlands	202	333	264
Poland	202	710	264
Portugal	202	203	264
Romania	202	255	264
Slovakia	202	105	264
Slovenia	202	220	264
Spain	202	177	264
Sweden	202	8	264

Source: (EEA 2022), (IPCC 2006).