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Towards an Efficient Decarbonization of Heat Use

Priorities of a European Heat Pump Action Plan

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Decarbonizing heat consumption is one of the most important, but also one of the most sensible steps towards a climate-neutral Europe. To promote social acceptance and create investment-friendly conditions, policymakers must ensure that decarbonization goes hand in hand with efficiency improvements and security of supply. This will only be feasible through a market-oriented regulatory approach. Due to their high efficiency and technical maturity, heat pumps will likely turn out to be the key technology in any such approach. However, a number of barriers and risk factors hamper their deployment. This has led stakeholders and Member States to urge the Commission to finally present a long-awaited Heat Pump Action Plan. This cepInput examines the arguments of the debate and recommends policy priorities.

- Tackling the financing constraints caused by high up-front costs is a key prerequisite for the widespread deployment of heat pumps. However, public support for replacing heating technologies and for conducting deep renovation must not be played off against each other, but should be treated as complementary.
- In order to facilitate grid management, Member States should create the regulatory conditions to incentivize an operation of heat pumps that is responsive to electricity supply. This does not only require economic incentives, but also the development of common technical standards to ensure interoperability.
- In order to overcome skill bottlenecks and speed up the dissemination of innovation, the EU should support the emergence of a European network of heat pump competence centers involving all relevant stakeholder groups. Besides organizing collaborative research on the design of innovative heat pump solutions, the centers could be engaged in the development of content for training programs and associated certificates.
- In addition to EU-wide carbon pricing through the new EU ETS-II, the stimulation of cost-minimizing decarbonization choices presupposes a harmonized and climate-oriented design of taxes and other levies on energy sources.

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1 Background

Accounting for about one third of total energy-related Greenhouse Gas (GHG) emissions in the EU,[1] the buildings sector has to be a key element in the EU's decarbonization strategy. In the scenario projections underlying the Commission's recommendation for a 2040 emissions reduction target, the buildings sector is expected to reach emissions reductions in a range of 88% to 93% compared to 1990.[2] To achieve this, massive energy efficiency improvements through renovation initiatives are required to be combined with a transformation of the fuel mix towards large-scale electrification.

Due to their high efficiency and technical maturity, heat pumps are considered the key technology for the decarbonization of heating. By integrating electricity from renewable sources into the buildings sector, they can bring about an end to the dependence on fossil fuels through sector coupling. Moreover, their role is not limited to building heat. They also represent a suitable heat source for a wide range of industrial applications. For these reasons, the Commission makes specific reference to heat pumps in their RePowerEU-Plan, formulating the target of installing at least 10 million additional heat pumps by 2027.[3] Subsequently, in the Green Deal Industrial Plan it set the goal of installing at least 30 million additional heat pumps by 2030.[4]

However, apart from their key role in technical perspective, heat pumps are also a paradigm for the manifold challenges and complexities of transition policies. This starts with the financing issue. While offering lower lifetime costs than fossil technologies under a wide range of setups, their uptake is hindered by the high up-front costs for purchase and installation, putting severe financing constraints on homeowners. Moreover, their massive roll-out is endangered by increasing skill bottlenecks in installation. With European heat pump production getting increasingly under cost pressure, new external dependencies are lurking around the corner, requiring demand-side support to be accompanied by measures to address supply security. Last but not least, the debate on heat pumps hints at the crucial importance of information provision and clear policy communication. In Germany, chaotic and ignorant political management has made heat pumps a symbol of a poorly planned, top-down energy transition, which has dealt a blow to investment in heat pumps.

Against this background, the previous Commission announced the preparation of a Heat Pump Action Plan, providing tools to overcome the various obstacles associated with heat pump deployment. According to the initial call for evidence, this was about to include measures addressing the financing gap as well as regulatory adjustments to ecodesign and energy labelling requirements.[5] However, originally to be published in 2023, the plan was postponed for the time after the European elections. Given the need for clear policy signals to fulfill the ambitious goals, this has created serious concerns by industry and national policymakers, leading 15 Member States to formulate a non-paper requesting

1 EEA (2023). Greenhouse gas emissions from energy use in buildings in Europe. European Environmental Agency.

2 European Commission (2024). Securing our future - Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society. Impact Assessment Report to the Communication – Part I. COM(2024) 63 final.

3 European Commission (2022a). REPowerEU Plan. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. SWD(2022) 230 final.

4 European Commission (2023a). A Green Deal Industrial Plan for the Net-Zero Age. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. COM(2023) 62 final.

5 European Commission (2023b). Heat pumps – action plan to accelerate roll-out across the EU. Call for Evidence.

a timely publication.[6] This cepInput contributes to the debate by providing an overview on existing market barriers and formulating policy proposals from a systemic perspective.

2 Role of heat pumps in the energy transition

2.1 Technologies

The basic idea of heat pumps is to make use of ambient heat energy as a source for heating or cooling purposes. The ambient energy is taken up by a liquid refrigerant which is then vaporized. Then, the energy is amplified by compressing the refrigerant and transferred by the pump to a heat sink. This can be a decentral building heating, a district heating or an industrial energy user. Due to the fact that the heat is not obtained through energy conversion, but transferred, high efficiency levels can be obtained. The energy output can exceed the power needed to run the heat pump by many times, thus clearly outperforming alternative heating technologies like gas boilers and electric heaters. Moreover, the cycle can be reversed to provide cooling instead of heating.

Heat pump technologies are usually distinguished by the specific heat source and the resulting energy form (see Figure 1). Four different heat sources are handled by the current generation of heat pumps: air, water, ground and waste heat. Air-source heat pumps are the most popular form of heat pumps, accounting for about 85% of all heat pumps sold worldwide.[7] Their crucial advantage is the comparatively low installation costs, as the heat can be directly captured from the surrounding air.

Ground-source and water-source heat pumps necessitate a more significant installation effort. Ground-source heat pumps require extensive groundwork to access sufficient heat. This can either the take the form of a vertical borehole of several meters' depth or a large horizontal network of pipes. This not only involves high monetary and time efforts, but – depending on the heating requirements – can also create high demand for space. Water-source heat pumps require significant water resources like rivers, lakes, ponds or groundwater nearby, with installation costs heavily depending on the specific geological conditions. However, an advantage of both ground-source and water-source systems compared to air-source systems is their higher efficiency during winter times, as ground and water sources remain warmer than the ambient air. This raises their attractiveness in geographical areas where the focus is clearly on the seasonal provision of heat. The technology decision is thus strongly influenced by the local surroundings and the individual heating needs. Moreover, system efficiency hinges on the choices for compressor, condenser and evaporator as the most critical components.

Industrial heat pumps running on waste heat represent an opportunity for industrial companies to optimize the efficiency of its internal energy flows by minimizing energy losses. Waste heat resulting from production process in the form of exhaust air or waste water is amplified by the heat pump and redirected to the production process in a closed loop system. In this way, automatically generated process heat that is too low to be directly reused can be kept in a cycle.

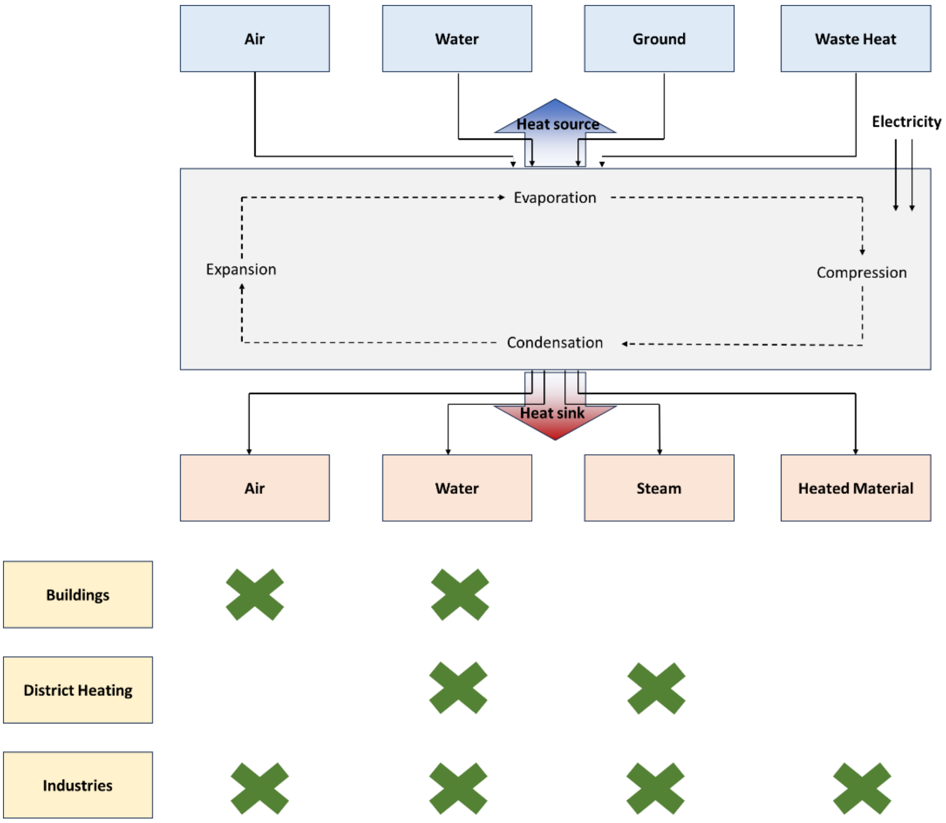
Regarding the heat sink, air-to-air heat pump systems are the most common form worldwide. The main discrepancy again concerns the trade-off between installation costs and efficiency, but also

[6] Member States (2024). The role of the heating and cooling sector in the EU2040 climate and energy framework. Joint non-paper by Latvia, Austria, Cyprus, Denmark, Estonia, France, Greece, Ireland, Lithuania, Luxembourg, Malta, Portugal, Slovakia, Slovenia, Spain.

[7] REN21 (2024). Renewables 2024 global status report. Renewable Energy Policy Network for the 21st Century.

compatibility issues. Air-to-air systems are more versatile and less costly to install. However, they are not compatible with existing central heating systems. Moreover, as they convey energy only through air, they do not contribute to the supply of hot water. For this, a secondary heat source is needed, potentially raising overall installation costs. For these reasons, air-to-water heat pumps are a common choice when replacing the heating source in existing buildings. They can be connected to existing water-transporting heating systems and reach higher efficiency levels than air-to-air systems. On the downside, due to the need for additional components like a hot water storage tank, installation costs as well as space requirements are comparatively high. Other forms of heat sinks like steam are designed for applications in district heating and industry. Based on these technologies, heat pumps can decarbonize a wide range of industrial processes.[8]

Figure 1: Types of heat pump systems



Source: IEA (2022); own adaptation.

2.2 Contributions by sector

2.2.1 Industrial and district heating and cooling

Heat pumps used as major energy source in industrial processes usually have a capacity of more than 200 Kilowatts. By running exclusively on electricity, they have the potential to fully decarbonize industrial energy when the electricity is obtained completely from renewable sources. Moreover, they can in many applications also offer efficiency gains compared to traditional fossil boilers.

Nevertheless, the application of heat pumps in industries is still underdeveloped and largely restricted to low-temperature processes below 100 Degrees Celsius. One reason are the technical limitations set

[8] IEA (2022). The future of heat pumps. World Energy Outlook Special Report. International Energy Agency.

by the heat requirements of certain production steps. For instance, certain chemical processes as well as steps in paper and food product manufacturing ask for the continuous provision of steam at temperatures of more than 200 Degrees Celsius. This not only requires high capacities but can also take conventional heat pumps to the limits of their efficient use. Given that these high-temperature processes are estimated to account for more than 60% of current total industrial heat use, this represents a serious constraint for the role of heat pumps as an industrial decarbonization tool. Nevertheless, current innovation efforts could raise the application spectrum significantly in the nearer future. At temperatures between 160 and 200 Degrees Celsius, commercial applications are already available, which are however costly due to their need for special types of compressors and refrigerants. For temperature applications of more than 200 Degrees Celsius, at least some prototypes exist. Their commercial breakthrough is expected still within the current decade. Table 1 presents an overview on the state of play.[9]

Table 1: Technology readiness levels of heat pumps for different temperature ranges

Temperature range	Technology Readiness Level (TRL)	Example processes
< 80 °C	TRL 11: Proof of market stability	Paper: De-inking Food: Concentration Chemical: Bio-reactions
80 °C to 100 °C	TRL 10: Commercial and competitive, but large-scale deployment achieved	Paper: Bleaching Food: Pasteurization Chemical: Boiling
100 °C to 140 °C	TRL 8-9: First-of-a-kind commercial applications in relevant environment	Paper: Drying Food: Evaporation Chemical: Concentration
140 °C to 160 °C	TRL 6-7: Pre-commercial demonstration	Paper: Pulp boiling Food: Drying Chemical: Distillation Various industries: Steam production
160 °C to 200 °C	TRL 4-5: Early to large prototype TRL 8-9: First-of-a-kind commercial applications for small-scale MVR systems and heat transformers	Various industries: High-temperature steam production
> 200 °C	TRL 4: Early prototype	Various industries: High-temperature processes

Source: IEA (2022); own representation.

District heating sets lower temperature requirements in a range of 60 to 135 Degrees Celsius, making heat pumps a more suitable candidate as a heat source. In these applications, particular benefits can be gained by combining large-scale heat pumps running on renewable local energy sources like PV electricity with waste-fired Combined Heat and Power (CHP) units. In this manner, a climate-friendly and at the same time steady central heat provision to homes can be guaranteed. Moreover, by combining heat pumps with a central thermal storage system, district heating can provide an important service to the overall energy system. Excess energy produced by heat pumps running exclusively on electricity from volatile renewable sources can be stored as heat energy in large tanks. In this way, electricity supply peaks can be cut off, thus combatting temporary imbalances and reducing

[9] See IEA (2022).

grid management costs. Water tanks are typically also cheaper as a storage solution than alternatives like battery storage. [10]

Currently, the dissemination of heat pumps as technology in central heating differs heavily among Member States, partly due to traditional differences in the importance of district heating networks. In the Scandinavian countries, especially in Sweden, large-scale heat pumps were widely installed in district heating systems already in the 1980s. Recently, countries like France and Italy have shown high growth rates in installation. Nevertheless, at a European scale, heat pumps currently make up only about 1% of the total installed capacity of district heating and cooling systems. For the near future, significant capacity growth is projected, whose realization will however critically depend on the further evolution of the regulatory framework.[11]

2.2.2 Building heating and cooling

In decentral heating of buildings, heat pumps are expected to make the most significant contribution to the integration of renewable energies and thus to the decarbonization goals. Besides their general efficiency advantage, this is also partly due to their flexibility. They can operate based on locally sourced electricity from PV rooftop systems, but also on electricity pooled from renewable sources located hundreds of kilometers away. Compared to alternative renewable heating technologies like wood pellet systems and gas boilers fueled by biomethane, they show less dependence on a specific and naturally limited resource. Moreover, in comparison to renewable hydrogen as another potential future alternative, i.e. hydrogen generated electrolytically by applying electricity from renewable sources, the direct use of electricity and the absence of conversion losses in heat pumps offers a much more favorable energy balance and thus a better exploitation of the limited available area for PV and wind power plants in Europe. In the future, this advantage could be increased by integrating further so-far unused energy sources like heat from household sewage into heat pump systems, thereby fully exploiting the flexibility of the technology.

In microeconomic perspective, heat pumps exhibit lower lifetime costs for households than gas boilers under many realistic setups. Yet, in the face of tough credit constraints, the high up-front costs of purchase and installation threaten to make them unaffordable for many home owners, in particular for those living in old unrenovated buildings. Their level is sensitive to the existing local infrastructure and climate conditions but tends to be significantly higher than in the case of fossil boilers. Depending on the configuration, installation efforts might not be limited to the heat pump system as such but can also require an upgrade of the electricity connection to cope with the additional electric capacity required. In cases where electricity is obtained from PV home production, the need for a stable heat source may entail the additional installation of a thermal storage tank. In the case of ground-source heat pumps, the costs of groundwork accrue on top of that.

Besides the issue of up-front costs, local surroundings can impede heat pumps from realizing their full technical potential, thus driving up operational costs for electricity costs.[12] For instance, low ambient

[10] Siddiqui, S., Macadam, J., & Barrett, M. (2021). The operation of district heating with heat pumps and thermal energy storage in a zero-emission scenario. Energy Reports, 7, 176-183.

[11] Euroheat & Power (2022). Large heat pumps in district heating and cooling systems. Report December 2022.

[12] As shown by Kozarcanin et al. (2020), expected mean temperature increases during this century will actually improve the economic balance of heat pumps vis-à-vis other heating technologies, but only at slow speed.
Kozarcanin, S., Hanna, R., Staffell, I., Gross, R., & Andresen, G. B. (2020). Impact of climate change on the cost-optimal mix of decentralised heat pump and gas boiler technologies in Europe. Energy Policy, 140, 111386.

temperatures in badly insulated buildings demand heat pumps to bridge a large temperature gap. Therefore, in order to reach potentially achievable high efficiency levels, there can be a need to upgrade the quality of building insulation and the intelligence of building energy management systems in parallel to heat-pump installations.[13] This stresses the complementarity between policy incentives for building renovation and for the decarbonization of heat sources.

Moreover, at system level, the widespread installation of heat pumps in buildings brings about a new challenge for electricity grids. The shift of residential heating to heat pumps implicates that household electricity demand will be not only be higher in total but will also be characterized by higher daily peaks. With increased adoption of battery-driven electric vehicles, these peaks could further intensify: when returning home from work, people could turn on their heating and at the same time charge their electric car. Moreover, there will be a new seasonal winter peak caused by the increasing heating needs. As a consequence, long-term grid planning needs to adapt to these new features, which can in some regions imply additional costs for capacity upgrades of distribution networks.[14]

Coping with this challenge not only requires incentives for local technical solutions like storage tanks, but also the ability of grid operators to exert direct control on heat pumps when needed. In Germany, the Smart Grid (SG) ready interface has been developed for this purpose a decade ago. In 2023, it has become a mandatory feature when applying for public financial support for heat pump investments in Germany.[15] Moreover, to reduce grid management costs, decentral economic incentives can fulfill an important function as well. This can include a more time-differentiated pattern of electricity prices (dynamic pricing) offered to households, generating incentives to reduce electricity consumption during peak load hours. Ideally, such signals should respond to unpredicted volatility on both supply and demand side. In addition, heat pump owners could be directly rewarded for providing system services to grid operators like offering capacity on reserve capacity markets or a contribution to the persistent task of frequency regulation.[16] Of course, all of these solutions require the general roll-out of smart meters and potential further grid communication devices in buildings in Europe.

3 Market situation

3.1 Supply chain characteristics

While being highly specific in detail, current commercial heat pump systems share the same basic components: a pump, a condenser, an evaporator, a refrigerant and an expansion valve. The pump itself is made of similar raw materials as conventional gas and oil boilers, mostly of reinforced steel. The condenser and the evaporator consist of many small tubes made of alloyed steel, copper or aluminium.[17] The refrigerant used for transporting the heat can either be of artificial or natural origin. Traditionally, hydrofluorocarbons (HFCs) are chosen, a group of artificial gases made from hydrogen, fluorine, carbon. Their strengths are their favorable thermodynamic properties and their low levels of toxicity. However, the fact that they are greenhouse gases has initiated a shift to alternative natural refrigerants like water, hydrocarbons, and ammonia, in the EU further accelerated by the F-Gas

[13] See IEA (2022).

[14] Toleikyte, A., Roca Reina, J. C., Volt, J., Carlsson, J., Lyons, L., Gasparella, A., ... & Letout, S. (2023). The heat pump wave: opportunities and challenges. Publications Office of the European Union, Luxembourg.

[15] GridX (2024). SG Ready.

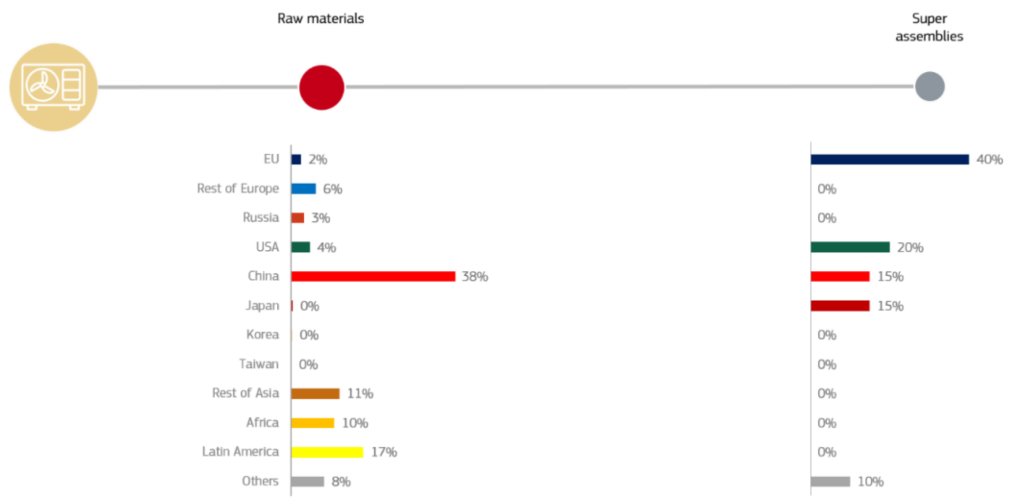
[16] Lee, Z. E., Sun, Q., Ma, Z., Wang, J., MacDonald, J. S., & Max Zhang, K. (2020). Providing grid services with heat pumps: A review. Journal of Engineering for Sustainable Buildings and Cities, 1(1), 011007.

[17] Scottish Enterprise (2023). Heat pumps and heating systems components analysis.

regulation (see Section 4). Moreover, improving the energy efficiency of heat pumps requires the incorporation of electronically controlled motors. These involve the additional use of semiconductor material.

In all, the complexity of heat pump design entails a dependence on a wide range of partly critical raw materials (especially copper) as well as on highly specialized skills for production and installation. Figure 2 presents the results of an analysis of global market shares in 2023 conducted by the EU Joint Research Centre (JRC).[18] Accordingly, while EU producers play an important role in the downstream stage of component assembly, making up almost half of the global market share, Europe faces a heavy external dependence in the raw material stage, foremost on China.

Figure 2: Key players along the supply chain of heat pumps



Source: JRC (2023a).

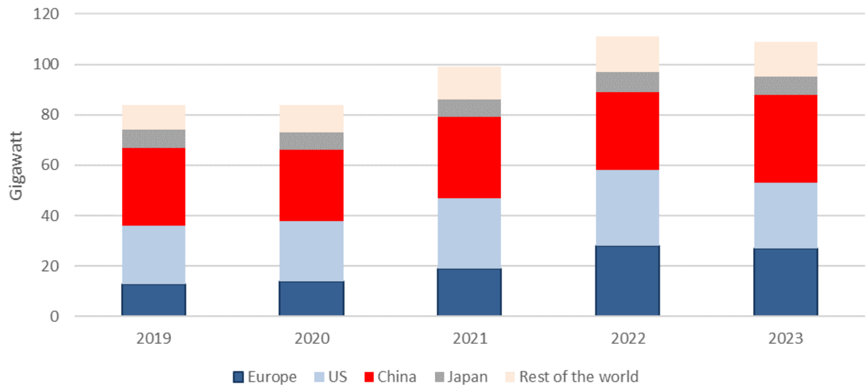
3.2 European market

In the past few years, Europe has become one of the key markets for heat pumps besides the US and China (see Figure 3).[19] For a long time, EU manufacturers could harness their technological leadership not only through high internal sales, but also considerable export strength. Yet, heat pump imports from third countries have shown continuous growth. Between 2020 and 2022, they have exploded, turning the EU from a net exporter to a net importer of heat pumps (see Figure 4). China is the dominant force behind this evolution, accounting in 2023 for 96.8% of EU imports in value terms.[20] At midstream level, there are also signs for a strong increase in market shares for certain critical components like compressors. This is the outcome of a targeted expansion strategy. Chinese producers can build on their large domestic market and the favourable conditions of China's long-term industrial strategy. Moreover, they are able to transfer their knowledge and innovation strength from

[18] JRC (2023a). Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study. Joint Research Centre at the European Commission.
[19] IEA (2024). Heat pumps – Latest findings. International Energy Agency.
[20] UN Comtrade (2024). UN Comtrade Database. United Nations.

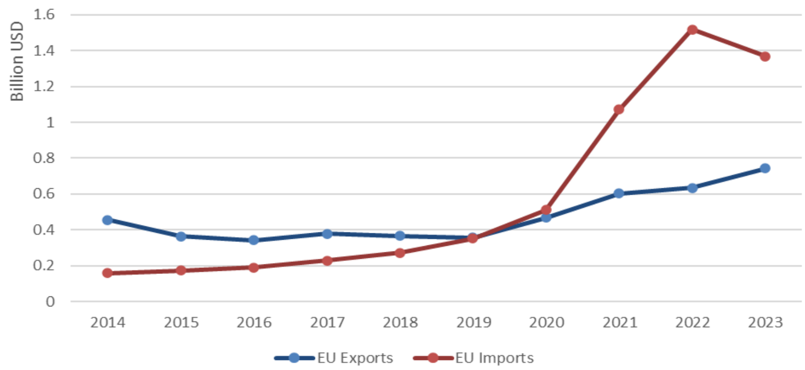
technologically related fields like air-conditioning and solar collectors, where China has been market leader for already a longer period.[21]

Figure 3: Heat pump sales by country or region



Source: IEA (2024).

Figure 4: Evolution of EU heat pump exports and imports



Source: UN Comtrade (2024); own illustration. HS code: 841861.

On the demand side, sales figures have witnessed a strong growth trend in Europe over the past ten years. The highest growth rates are observed for air-to-water heat pump systems. In 2022, they overtook air-to-air systems as the most frequent specification, likely due to their superior efficiency. Yet, after strong annual growth in 2021 and 2022, heat pump sales dropped in 2023 for the first time in a whole decade. In country comparison, the by far most significant drops happened in Italy, followed by Poland and Finland. Sales increases in other countries were unable to compensate for these declines.[22] As a consequence, the EU has been thrown back on its way towards fulfilling its long-term installation goals. The about 24 million heat pumps currently installed in the EU are still far less than the 60 million heat pumps needed by 2030 according to the impact assessment of the Commission's

[21] European Commission (2022b). Heat Pumps in the European Union 2022. Status Report on Technology Development, Trends, Value Chains and Markets.

[22] EHPA (2024a). European heat pump market and statistics report 2024 – Executive Summary. European Heat Pump Association.

Climate goals 2040 Communication.[23] The European Heat Pump Association (EHPA) stresses that with annual sales remaining at 2023 levels the total stock will only raise to 45 million heat pumps by 2030.[24]

3.3 Market risks

3.3.1 Supply risks

Among the various mineral resources relevant for the supply chain of heat pump systems, copper is assessed to possess the highest critically in the near future. While EU import dependence is rather limited compared other critical metals like rare earths and lithium,[25] the strong global demand increase expected for the upcoming years due to the general electrification trend is threaten to cause shortages. S&P Global estimates that global copper production needs to double until 2035 to meet the growing demand. This demands an effort far beyond current investments in mining capacities.[26] Moreover, mining data shows that copper ore grades, the share of copper included on average in copper ores, are declining.[27] This could reduce investment incentives into new mines. For these reasons, the European Commission has added copper to its list of critical raw materials in the most recent update.[28]

Further raw material risks relate to the availability of semiconductors for the electric control units of heat pumps. Even though the long-lasting semiconductor crisis seems finally to have ended, the high complexity and granularity of semiconductor supply chains, as well as the strong international division of labour, continue to impose structural supply risks. First, the need to transport components and equipment across the globe implies a particularly high exposure towards disruptions in global shipping routes caused by natural disasters or armed conflicts. Second, the ongoing "Chip war" between the US and China bears the risk of further escalation, leading to a spiral new trade-restrictive measures on all sides, including the EU.[29] With technological progress, demand for semiconductors by heat pump manufacturers is likely to rise, as heat pump systems are upgraded to more complex forms of energy management.

Apart from risks to material supply, the realization of the ambitious growth goals is also threatened by skill bottlenecks in both production and installation (installers, plumbers, electricians) of heat pumps. The EHPA forecasts that around 500,000 skilled workers will be needed to manage the roll-out envisaged by the RePowerEU plan, while the number of employees at the beginning of 2023 was estimated to be only around 117,000.[30] However, an analysis by the JRC reveals that job vacancy rates in sectors relevant to the energy transition (manufacturing, energy supply, construction, scientific and technical activities) have doubled from the second quarter of 2020 to the first quarter of 2023. This was apparently not exclusively grounded in the fast crisis recovery, but also influenced by the long-term trend of a shrinking working age population. Moreover, the structural demand changes on the labour market caused by the twin transition also raise the risk of skill mismatches in growth sectors

[23] See European Commission (2024).
[24] See EHPA (2024).
[25] Wolf, A. (2023). Recycling green technologies of the future. cepInput No.10/2023.
[26] S&P Global (2023). World copper deficit could hit record; demand seen doubling by 2035.
[27] Copper Development Association (2023). Why copper is a critical metal.
[28] European Union (2024a). Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020Text with EEA relevance.
[29] Z2Data (2024). The Five Biggest Disruptions to the Semiconductor Supply Chain in 2024.
[30] EHPA (2023). Wanted: half a million heat pump workers. European Heat Pump Association.

like heat pumps. According to the latest European Skills and Jobs Survey, upskilling needs are particularly high in energy supply and manufacturing.[31] At the same time, only a minority of workers participated recently in training activities. In 2022, the EU-wide participation rate amounted to 24% for manufacturing workers and to 34% for workers in energy supply.[32]

3.3.2 Demand risks

On the demand side, risks primarily concern the roll-out of heat pumps in decentral building heating. This starts with physical space restrictions. While space requirements for the pump outside the building can be effectively managed by the technology choice (e.g. by choosing an air-source instead of a ground-source heat pump), the heat exchanger unit requires in any case sufficient additional internal space.[33] Increasing the efficiency of the system typically requires larger units, implying a trade-off between saving energy costs and space.[34] Moreover, to achieve the electrification rates necessary for decarbonizing the buildings sector, the retrofit of existing buildings with heat pumps requires a significant boost. In principle, the diversity of heat pump solutions offers a large spectrum of tailor-made solutions for different existing building types. However, the energy performance of the chosen variant will in any case depend on the flow temperatures of the heating system. In old, poorly insulated buildings it will be comparatively high, which lowers the performance ratio of the pumps and thus potentially ruins the economics. Simultaneous renovation efforts like retrofitting the insulation on the façade or replacing old radiators can improve the performance but come with additional up-front costs and temporary loss of living comfort.

Another factor potentially impairing heat pump demand in Europe is electricity prices. For households examining the returns from replacing their heating source, the ratio of electricity to fossil fuel prices is a central metric. A common rule-of-thumb is that electricity should cost less than twice as much as natural gas for heat pumps to bring cost savings compared to gas boilers.[35] In this respect, with current household energy prices, the evaluation would come to very different conclusions in different Member States, with countries like Germany and Italy exceeding this maximum threshold (see Figure 5).[36] This discrepancy exists even though there is some direct connection between electricity and gas prices through the frequent role of gas power plants as price-setters in electricity wholesale trade. One likely reason are discrepancies in the tax burden on electricity vis-à-vis natural gas. Besides specific energy taxes, this can be due to differences in network fees or the existence of levies for financing the promotion of renewable energies. Moreover, at the European level, the fact that electricity generation has for a long time been subject to carbon pricing through the Emissions Trading Scheme (ETS), while gas consumption by private households has not, has contributed to a worsening of the energy price relation from the perspective of heat pumps. However, with the approved implementation of an own Emissions Trading Scheme (ETS-II) for the buildings and transport sector, this is about to change in the nearer future (see Section 4).

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31 JRC (2023b). Skills for the energy transition in the changing labour market. Joint Research Centre at the European Commission.

32 Eurostat (2024a). Participation rate of employees in education and training. Eurostat Database.

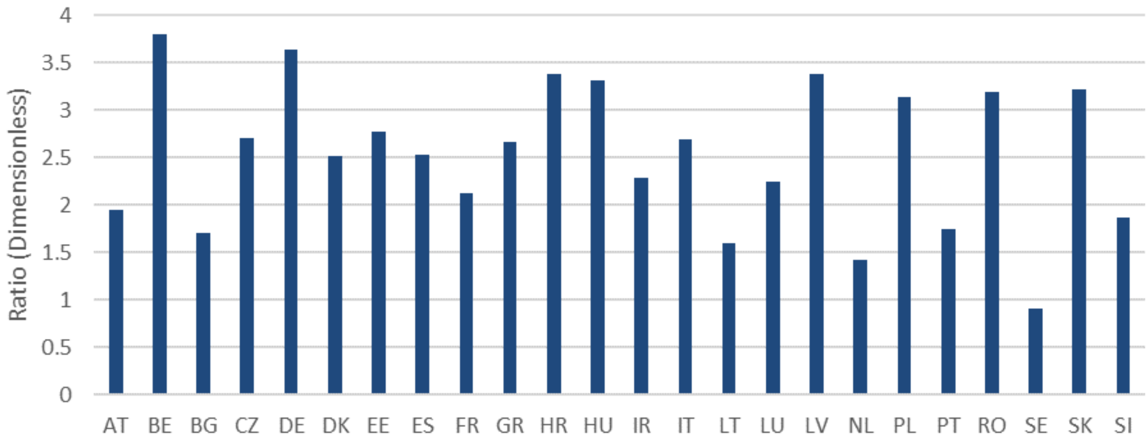
33 Wolf (2024). Are heat pumps suitable for old buildings?

34 Swegon (2023). Space requirements for heat pump solutions.

35 See EHPA (2024a).

36 Eurostat (2024b). Energy statistics – natural gas and electricity prices. Eurostat Database.

Figure 5: Ratio household electricity prices to natural gas prices in the second half of 2023



Source: Eurostat (2024b); own calculations.

Finally, regulatory complexity and uncertainty can also represent a serious demand risk. Untransparent and unstable rules on public investment support and energy performance standards can lead to information overload and make investments in heat pumps vulnerable to market disruptions. Recent developments in Italy are a good example of the latter. The generous tax deductions for heating investments introduced by the Conti government in 2020 covered more than 100 per cent of the costs. This created an unprecedented sales boom for both heat pumps and natural gas heating. As soon as the Meloni government stopped the programme in 2023, the market collapsed almost completely.[37] Disruptions like this feed a wait-and-see attitude among homeowners that is increasingly difficult to overcome with new support measures. The endless discussions and amendments surrounding the 2023 revision of the Building Energy Act in Germany are another example of a well-intentioned policy having the opposite of the expected positive incentive effect.[38]

4 Relevant EU regulatory framework

4.1 Strategies

In 2016, with the EU Strategy on Heating and Cooling, the Commission made a first major step towards making heating and cooling in Europe more efficient and sustainable. It aimed to address barriers to energy renovation and the exchange of heating equipment. In the strategy, electrification through heat pumps was already mentioned as one particular promising way to raise efficiency in the buildings sector. The strategy announced a deeper analysis of how to achieve an efficient decarbonization within the reviews of its renewable energy and energy efficiency laws.[39] The next major strategic step was the publication of the Communication "A Renovation Wave for Europe" in 2020. Published during the economic downturn in the first phase of the COViD-19 pandemic, it aimed to stimulate deep renovation investments including integration of renewables through targeted incentives. The idea was to combine short-term business cycle impulses with a boost to long-term structural modernization of

[37] Blackout News (2023). Heat pumps in Italy: subsidies exhausted, market collapses.
[38] EHPA (2024b). Pump it down: why heat pump sales dropped in 2023. European Heat Pump Assocation.
[39] European Commission (2016). An EU Strategy on Heating and Cooling. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. COM(2016) 51 final.

the building stock. It stressed the central role of building renovation within national recovery plans and recommended additional EU long-term funding of renovation activities beyond the temporary Recovery and Resilience Facility.[40]

In 2021, the comprehensive Fit-for-55 package brought major regulatory changes to EU heating markets. Besides goals and measures directly targeting heat sources (see below), the proposal to introduce an own Emissions Trading Scheme (ETS-II) for the buildings and transport sector marked a milestone towards a homogeneous carbon pricing for building heat.[41] Another major boost in political attention brought the year 2022 with the Russian invasion in the Ukraine and the resulting gas supply crisis in the EU. Besides a series of short-term stabilization measures focused on gas markets, the Commission was reacting swiftly with a new long-term strategy on achieving energy independence from Russia called RePowerEU. It involved new goals for a more rapid switch to renewable heat sources, including a doubling of the current deployment rate of individual heat pumps, resulting in additional 10 million heat pumps over the subsequent five years. To support supply chains for heat pump technologies, the Commission announced a revision of life-cycle sustainability requirements (ecodesign, energy labelling) and support of initiatives by Member States to establish Important Projects of Common European Interest (IPCEI) on heat pump technology development.[42]

4.2 Specific regulation

4.2.1 Renewable energy goals

The sector-specific goals for the deployment of renewable energies set by the current version of the Renewable Energy Directive (RED III) are designed to have a stimulating impact on heat pump installations. It asks Member States to define indicative national shares for the use of renewable energy produced on-site or taken from the grid in buildings in 2030 within their National Energy and Climate Plans (NECPs). These shares are supposed to be compatible with an EU-wide target of at least 49% of energy from renewable sources in the building sector. Moreover, targets mandatory for each Member State are defined for the use of renewable energy in the heating and cooling sector. Over the period 2021-2025 (2026-2030), the average annual increase shall amount 0.8% (1.1%). To reach these targets, Member States shall implement dedicated support measures like financial incentives to the installation of renewable heating and cooling equipment, installation of this equipment in public buildings and requirements for regions regarding renewable heat planning. Specific national targets are defined for renewables and waste heat in district heating and cooling. Its share in energy input shall on average increase from year to year by an indicative 2.2 percentage points over the period 2021 to 2030. The national measures implemented to reach these goals shall be described in the NECPs.[43]

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[40] European Commission (2020). A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. COM(2020) 662 final.

[41] European Union (2023a). Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system.

[42] See European Commission (2022a).

[43] European Union (2023b). Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652.

4.2.2 Energy performance of buildings

The Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive (EED) together define requirements and incentives for improving the energy efficiency of heat use in buildings. This also affects the performance and thus the economic returns of heat pumps. The EPBD requires Member States to set up national building renovation plans as a strategic policy tool to achieve the long-term goal of a highly efficient and fully decarbonized national building stock by 2050. This shall involve a roadmap with specific medium-term targets and policy measures. Moreover, for new buildings and buildings undergoing major renovations, Member States shall set and monitor minimum energy performance requirements for those buildings parts that are essential for the energy performance of the building. From 2030 onwards, all new buildings shall be zero-emission buildings, i.e. have a very high energy performance, require zero or a very low amount of energy and produce zero on-site carbon emissions from fossil fuels. For public buildings, this goal is already set for 2028. Moreover, Member States shall set technical requirements for the replacement and upgrading of existing technical building systems, to ensure the proper installation and a cost-minimal energy consumption. Specifically, from May 29th, 2026, new buildings and buildings undergoing major renovations shall be required to be equipped with electronic monitoring systems and be able to adjust their energy consumption to external signals.[44]

These concrete measures are complemented by the EED and its general goal of lowering EU final energy consumption by at least 11.7% in 2030 compared to the 2020 EU reference scenario. The public sector shall assume a leading role in this, reaching the specific target of reducing its final energy consumption by 1.9% each year until 2030. This represents an important impetus for installing highly efficient heat pumps in public buildings. This is supported by public procurement requirements wh public authorities to only purchase products with high energy-efficiency performance.[45]

4.2.3 Air pollution provisions

Heat pumps are also affected by the EU's regulatory approach towards air pollution, as it imposes restrictions on the use of certain synthetic refrigerants due to their high global warming potential. On February 7th, 2024, a new F-Gas regulation was adopted. It implements a more ambitious quota system for hydrofluorocarbons (HFCs) on the EU market, including those used within heat pump systems. It defines a maximum annual amount that can be placed on the market, which is gradually reduced over time and becomes zero in 2050. This maximum amount is split into quotas allocated to single producers and importers.[46] This procedure implies continuously increasing scarcity and at least in the short-term rising prices for HFCs, thus pushing heat pump producers to switch to more sustainable refrigerants like ammonia and water as an alternative. Moreover, the debate on a general EU ban of Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) within the framework of the REACH regulation is still ongoing, because of their slow natural degradation. This would affect heat pumps using hydrofluoric-olefins (HFOs) as refrigerants, as these contain PFAS.[47]

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[44] European Union (2024b). Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings.

[45] European Union (2023c). Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955

[46] European Union (2024c). Regulation (EU) 2024/573 of the European Parliament and of the Council of 7 February 2024 on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014.

[47] Clade (2024). PFAS: The heat pump industry's toxic pollution secret.

4.2.4 Electricity pricing

Recently, the Commission has made some proposals affecting price levels and contracts for consumer electricity, and thus the economic performance of heat pumps. The reform of electricity markets, consisting of a Directive and a Regulation, has been adopted on June 13th 2024. The Regulation introduces the concept of non-fossil flexibility support schemes. These consist of subsidies to facilities for participating in capacity mechanisms to stabilize the electricity grid. Besides generation capacity, this also includes demand side response facilities like heat pumps. In this way, heat pump owners can receive public support for adjusting their demand according to the needs of the grid. France has already implemented a corresponding support scheme.[48] In designing these measures, Member States shall ensure a proper alignment with electricity markets, i.e. avoid a distortive influence on markets and grid management processes.[49] Moreover, the new Directive gives electricity customers with smart meters the right to demand dynamic price contracts, i.e. contracts with prices that vary over time. Electricity suppliers must provide customers with all the information necessary to understand the costs and risks of such contracts.[50] Finally, regarding the ratio of electricity versus fossil fuel prices, the currently stuck negotiations on the revision of the Energy Taxation Directive are of high relevance. It defines minimum rates for national excise taxes on energy carriers. The proposal by the Commission foresees a large spread in minimum tax rates between fossil fuels on the one hand and electricity and renewable fuels on the other, to incentivize the use of low-emission energy.[51]

4.2.5 Production goals

The Net-Zero Industry Act defines for the first-time concrete targets for the deployment of net-zero technology production capacity in the EU. By 2030, domestic manufacturing capacity for net-zero technologies, including heat pumps, shall amount to 40% of the EU's annual deployment needs. Moreover, by 2040, it shall capture 15% of the world market for these technologies. To reach the designated goals, the Net-Zero Industry Act includes a range of support measures applicable to projects creating production capacities for the listed technologies. The support framework is divided into two stages. First, a basic form of support applies to all net-zero technology manufacturing projects. This includes maximum time-limits on permit procedures of 12 months for small-scale (< 1 GW capacity) and 18 months for large-scale (≥ 1 GW) projects. Moreover, to support domestic manufacturing from the demand side, the Net-Zero Industry Act envisages new criteria for public procurement procedures involving net-zero technologies. This includes mandatory minimum requirements for the environmental sustainability of production, which will be spelled out later by an implementing act. In addition, new resilience criteria are defined for public tenders, including the rule that no more than 50% of the EU's supply of a net-zero technology may stem from a single third country.

Specific rules apply to so-called strategic net-zero projects. Net-zero technology manufacturing projects must be recognized by Member States as "strategic" if they contribute to the capacity goals

[48] European Commission (2023). Commission approves €1.3 billion French State aid scheme to support non-fossil technologies to ensure electricity supply matches demand.

[49] European Union (2024d). Regulation (EU) 2024/1747 of the European Parliament and of the Council of 13 June 2024 amending Regulations (EU) 2019/942 and (EU) 2019/943 as regards improving the Union's electricity market design.

[50] European Union (2024e). Directive (EU) 2024/1711 of the European Parliament and of the Council of 13 June 2024 amending Directives (EU) 2018/2001 and (EU) 2019/944 as regards improving the Union's electricity market design

[51] European Commission (2021). Proposal for a Council Directive restructuring the Union framework for the taxation of energy products and electricity.

of the legislation, provide European industries with the best available technologies and fulfill at least one other criterion on each of the two lists of criteria. The first list includes the production of net-zero technologies for which there is a high dependence on imports (third country share of more than 50 %), the production of net-zero technologies with a crucial role for EU resilience as well as projects with significant contributions to the 2030 climate or energy objectives of the EU. The second list includes as alternative criteria the presence of upskilling and reskilling measures or contributions to the competitiveness of SMEs. Strategic net-zero projects must be assigned a special priority status in national permit granting procedures including the speed of handling any lawsuits related to permit granting. Even stricter time limits apply to the permit granting procedure itself, consisting of 9 months for small-scale (< 1 GW capacity) and 12 months for large-scale (≥ 1 GW) projects. Moreover, strategic net-zero projects can apply for specific advice on project financing by the newly established Net-Zero Europe Platform.[52]

5 Policy recommendations

Promoting the decarbonization of heat consumption is in many ways even more challenging than the decarbonization of electricity generation. Policymakers have to deal with an enormous variety of potential technological solutions, the technical and economic feasibility of which varies greatly according to local circumstances. They have to address the buildings sector as a major heat consumer and are therefore directly confronted with fears of energy poverty, which means that any policy will be subject to intense public scrutiny. They also have to deal with the closer coupling of electricity and heat flows caused by the electrification trend and with its impact on the overall cost of managing the energy system. Against this background, policy strategies are always at risk of either overlooking technological limitations or getting lost in the detailed regulatory needs of specific technological setups. For the EU in particular, these risks are acute, as it has to deal with Member States that by tradition exhibit large discrepancies in the mix of heat sources and in the relevant national regulations. The only viable solution is a mixed approach: Providing strong general guidelines based on common policy targets at the central level, while ensuring a maximum of technological flexibility in implementation.

When designing a framework for the further promotion of heat pumps, policies should primarily aim at exploiting the central role of heat pumps in decarbonizing heat consumption at low overall system costs, while minimizing internal and external risks on this path. This requires transparent and consistent economic incentives. Institutions must also be put in place to ensure an EU-wide exchange of information on technology options between heat pump manufacturers, installers and users, and to combat the spread of misinformation to the public. Finally, as with other fast-developing strategic net-zero technologies, policy management requires continuous monitoring of cross-border supply chains and an exchange between policymakers and industry to address emerging supply risks. In this spirit, we offer some broad suggestions for policy priorities.

Enforce clear carbon price signals

Navigating through the diversity of decarbonization options requires decentralized steering through carbon prices. These need to be implemented across the EU and aligned with overarching emission

52 European Union (2024f). Regulation (EU) 2024/1735 of the European Parliament and of the Council of 13 June 2024 on establishing a framework of measures for strengthening Europe's net-zero technology manufacturing ecosystem and amending Regulation (EU) 2018/1724

reduction targets. This will encourage undistorted technology choices, driven primarily by abatement costs, and thus focus the use of heat pumps in areas where they offer the greatest efficiency benefits. In this respect, the success of the forthcoming ETS-II will be crucial for the further decarbonization of the buildings sector and the balance with industrial emissions reductions. In its implementation and further development, policy makers need to consider the potential negative impact of carbon price uncertainty on early investments in heat pumps. It exacerbates the constraints faced by homeowners in financing the up-front costs of heat pump systems by increasing uncertainty about the extent and timing of future payback in terms of energy cost savings. In turn, a wait-and-see attitude on the part of homeowners could have serious consequences for the long-term effectiveness of the scheme: high demand for allowances in the start-up phase would put strong upward pressure on allowance prices, leading to calls for an expansion of the supply of allowances through special auctions or a less ambitious future reduction of the cap. Avoiding this situation requires a credible commitment to future mitigation pathways and targeted support to overcome financing constraints (see below).

Harmonize energy taxation according to overarching climate policy goals

In addition to general carbon pricing, the optimal choice of abatement technologies in the heating sector also requires a harmonized and undistorted design of taxes and other levies on energy sources. To this end, the currently stalled negotiations on the reform of the EU Energy Taxation Directive must finally be brought to a successful conclusion. As originally proposed by the Commission, the adopted version should include a significant spread between the minimum levels of taxation set for fossil fuels and those set for renewable heating fuels and electricity. In turn, Member States should implement the reform consistently, meaning that the actual tax rates on energy sources used in climate-friendly energy technologies are set close enough to the minimum tax rate to support their implementation. In particular, the ratio between the retail prices of gas and electricity should be a benchmark to ensure that the efficiency advantage of heat pumps is sufficiently reflected. In addition, Member States should consider ways to reduce electricity network charges and other specific non-market price components of electricity without distorting market pricing. Such an approach would complement the incentive effects of the future ETS-II and thus serve to reduce political pressure to dilute its function.

Overcome financing constraints through a holistic approach

Tackling the financing constraints caused by high up-front costs is a key prerequisite not only for the widespread deployment of heat pumps, but also for a cost-minimizing decarbonization of the heating sector in general. In addition to continued fiscal support at national level, the EU Social Climate Fund can become another important financing instrument for heat pumps with the start of ETS-II. However, its targeted use will depend on the preparation and implementation of the Social Climate Plans by Member States. In doing so, they should follow the good practice recommendations. Support programs for heating investments should be designed to take into account the characteristics of the wide range of building types and technological solutions that exist in each country. Public support for replacing heating technologies and for deep renovation must not be played off against each other, but should be seen as complementary. For heat pumps in particular, the efficiency effect of combining installation with insulation measures or replacing radiators must be fully recognized. In order to avoid homeowners having to deal with different administrative bodies, it may be useful to bundle single applications for permits and subsidies in administrative one-stop-shops.

Strengthen incentives for system-friendly heat pump operation

In order to facilitate grid management and to fully realize the savings potential of heat pumps, Member States should work on creating the regulatory conditions to incentivize flexible operation. In particular, they should rapidly implement the relevant measures included in the new Electricity Market Directive and Regulation. Accordingly, customers with smart meters should have the right to request dynamic electricity price contracts. In addition, more Member States should make use of the possibility to introduce non-fossil flexibility support schemes to promote the use of heat pumps as a demand response instrument for the grid. In order to make an effective contribution, business models need to be developed that bring together a large number of small heat pumps. In addition to financial support, this will require the development of common technical standards to ensure interoperability. Finally, Member States need to do more to remove barriers and increase acceptance of smart meters in EU households.

Support the creation of an EU-wide network of heat pump competence centers

The technological specificities of heat pumps and the dynamic development of the technology require a continuous exchange of knowledge and training, in particular with regard to building assessment and system installation. In order to create a common knowledge base and speed up the dissemination of innovation, the EU should support the emergence of a network of competence centers spread across Europe. It should involve companies along the entire European heat pump supply chain, as well as representatives of installers, academia and consumer advisors. In addition to organizing collaborative work on the design of innovative heat pump solutions, the centers should be involved in the development of content for training programs and associated certificates, thus fulfilling the function of a Net-Zero Industry Academy as foreseen in the Net-Zero Industry Act. A special focus should be placed on the re-skilling of workers from sectors negatively affected by the ongoing structural change. They should also work with universities to discuss options for expanding heat pump-specific content in the curricula of technical bachelor and master programs.

Institutionalize EU-wide heat pump market and policy monitoring

Statistical knowledge of heat pump supply chains in Europe and beyond is still scarce and decentralized. In order to better monitor the market position of European companies at each stage of production and to identify potential supply risks at an early stage, the EU should establish a monitoring framework, including regular detailed reports on the market situation by the Joint Research Centre. Member States' policies on buildings and industrial heat use should also be monitored to identify gaps and inconsistencies that could jeopardize EU-wide targets.

6 Conclusion

Decarbonizing heat consumption is one of the most important and sensible steps towards a climate-neutral Europe. To promote social acceptance and create investment-friendly conditions, policymakers must ensure that decarbonization goes hand in hand with efficiency improvements and security of supply. To achieve this, existing barriers to the commercialization of low-cost alternative heat sources must be urgently removed. Heat pumps deserve to be at the center of these policy strategies. They offer unbeatable energy performance, can be adapted to a wide range of circumstances and are key to the system integration of domestic renewable energy from wind and solar. Tackling regulatory fragmentation across Member States, severe financing constraints and external supply risks requires a coordinated European approach. It is therefore high time for the Commission to launch a heat pump action plan to provide new impetus for faster market uptake.

When designing a support strategy, the aim should be to enable heat pumps to monetize their natural system-wide cost advantages on markets, without excluding alternative climate-friendly heat sources. At the same time, it is important that incentives to switch heating technology are not played off against the need to increase investment in deep renovation. Indeed, in many cases only a combined investment will allow the efficiency benefits of heat pumps to be realized in existing buildings. In addition to strengthening the guiding role of carbon pricing in the buildings sector, a variety of regulatory and non-regulatory measures will be needed to overcome market barriers. Policy-related price disadvantages of electricity as a heat source should be removed by reducing the tax burden on industrial and domestic electricity consumption and by reducing tax heterogeneity between Member States.

Support schemes and technical regulations for time-flexible operation of heat pumps should be put in place, allowing a quick response to real-time market signals and thus making heat pumps an effective tool for energy system management. In addition, an EU-wide network of competence centers would help to speed up the diffusion of innovation and could address emerging skills bottlenecks. Finally, centralized information gathering and policy monitoring will be essential to identify supply risks at an early stage and to harmonize the strategic approach to renewable energy support in the heating sector. If successful, the EU heat pump strategy could become a model for an intelligent form of industrial policy, combining decentralized steering through market prices with targeted adjustments of framework conditions.

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