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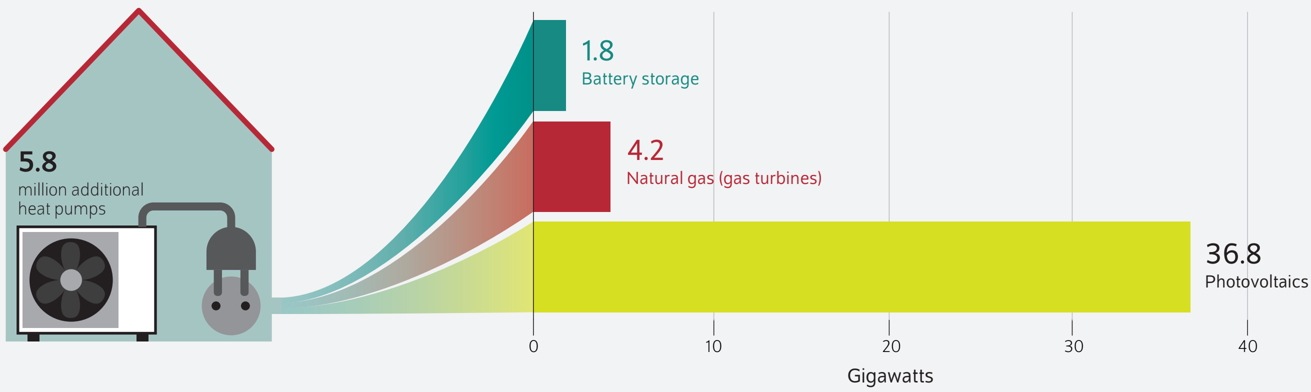
AT A GLANCE

Expanding solar energy capacity to power the transition to heat pumps

By Alexander Roth, Carlos Gaete-Morales, Adeline Guéret, Dana Kirchem, Martin Kittel, and Wolf-Peter Schill

- By increasing the use of heat pumps, carbon emissions and natural gas imports can be reduced
- Renewable energy sources must be expanded to meet the additional electricity demand sustainably
- Model calculations for 2030 show how the electricity sector needs to adjust for the transition to heat pumps
- Costs associated with the transition are low from a macroeconomic perspective; there are even savings when natural gas prices remain high
- Policymakers should drive the transition forward with an ambitious and coordinated program

Increase in power plant capacity to meet the electricity demand of additional heat pumps in 2030[1]



Source: Authors' own calculations using DIETER, an open-source electricity sector model.

1 Compared to the reference scenario with 1.7 million heat pumps.

FROM THE AUTHORS

Heat pumps can help reduce carbon emissions as well as our dependence on Russian natural gas imports—and can even lead to macroeconomic savings if natural gas prices remain high.

— Alexander Roth —

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Expanding solar energy capacity to power the transition to heat pumps

By Alexander Roth, Carlos Gaete-Morales, Adeline Guéret, Dana Kirchem, Martin Kittel, and Wolf-Peter Schill

ABSTRACT

Increasing the use of heat pumps is an important measure for reducing carbon emissions in the heating sector as well as natural gas imports. This report uses an electricity sector model to investigate the effects of an accelerated expansion of the heat pump stock on the German electricity sector in 2030. Adding around six million heat pumps would increase electricity demand by nine percent in 2030; to meet this demand with solar energy, photovoltaic capacity would have to be expanded by 23 percent. Natural gas imports could be reduced by 15 percent. From a macroeconomic perspective, the higher the price of natural gas, the more advantageous it becomes to increase the use of heat pumps. Accelerating the transition to heat pumps, however, requires an ambitious and coordinated policy program that also focuses on the production capacity of heat pumps and on providing advanced training to workers—a kind of "Apollo program" for heat pumps.

Following the Russian invasion of Ukraine, both Germany and the EU are attempting to reduce their dependence on Russian energy imports as quickly as possible.[1] Natural gas, however, poses a particular problem. On the one hand, pipeline-based natural gas imports are more challenging to replace in the short term than other imported energy sources.[2] On the other hand, Russia's importance to the German gas supply is enormous.[3]

Natural gas plays a crucial role in the German energy supply: In 2021, it made up nearly 27 percent of primary energy consumption.[4] In addition to industry (37 percent of German natural gas sales in 2021), natural gas is used primarily by private households to provide space heating (31 percent). Refrigeration, district heating, and the electricity supply use nine percent each.[5]

Replacing gas heating systems with heat pumps—a prudent transition in light of the climate crisis—can significantly reduce German dependence on Russian natural gas imports. However, such a transition results in a higher level of electricity consumption. Using an open-source electricity sector model developed at DIW Berlin, the impact of an expanded heat pump stock in Germany on the electricity sector in 2030 is investigated.[6] Moreover, the additional heat pump-related costs are compared with the costs saved on natural gas.

1 Cf. Bundesministerium für Wirtschaft und Klimaschutz, *Versorgungssicherheit stärken – Abhängigkeiten reduzieren* (2022) (in German; available online. Accessed on May 13, 2022. This applies to all other online sources in this report unless stated otherwise.); European Commission, *REPowerEU: Joint European Action for more affordable, secure and sustainable energy* (Strasbourg: 2022) (available online).

2 Cf. Franziska Holz et al., "Europa kann die Abhängigkeit von Russlands Gaslieferungen durch Diversifikation und Energiesparen senken," *DIW aktuell* 81 (2022) (in German; available online); Franziska Holz et al., "Energy supply security in Germany can be guaranteed even without natural gas from Russia," *DIW focus* 7 (2022) (available online).

3 Germany is a natural gas transit country. Imported natural gas is partially passed on to neighboring countries. Cf. DIW Berlin's KoaVTracker, which is continually updated (available online; in German).

4 Arbeitsgemeinschaft Energiebilanzen, *Energieverbrauch in Deutschland im Jahr 2021* (2022) (in German; available online).

5 Authors' own calculations based on Arbeitsgemeinschaft Energiebilanzen, *Energieverbrauch in Deutschland.*

6 The analysis was carried out in the BMBF-funded research project Ariadne, FKZ 03SFK5N0.

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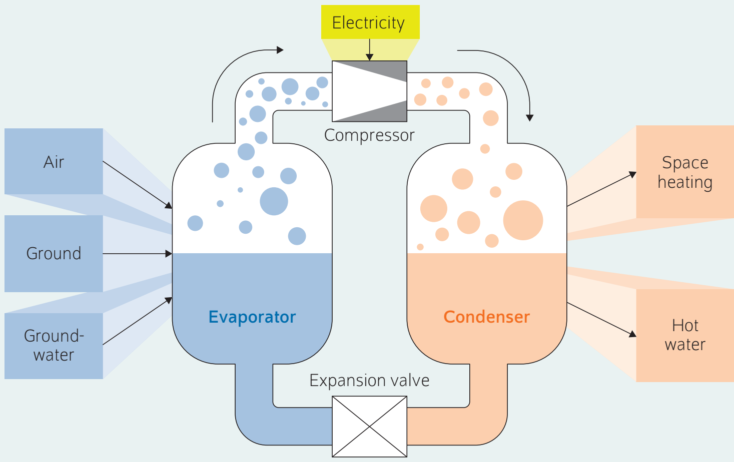
Box 1

The heating cycle of heat pumps

A heat pump extracts heat from the environment of a building and transfers it at a higher temperature into the building as heating energy. Essentially, heat pumps function like a refrigerator in reverse, which extracts heat from its interior and releases it into the environment. A heat pump is made up of four elements (Figure): a compressor, two heat exchangers (a condenser and an evaporator), and an expansion valve, through which a coolant with a low boiling point circulates. When heat energy from outside hits the evaporator, it is transferred to the coolant and evaporates. The refrigerant vapor is then directed to the compressor, which is powered by electricity. Compressing the gas raises its temperature to one that can be used for space heating. Heat is then extracted from the compressed, warmer steam via condensation in the condenser and is distributed into the building. Finally, the liquid refrigerant returns to the expansion valve, where the pressure is reduced. The cycle then repeats itself again.

Figure

Schematic illustration



Note: Blue represents low temperatures, red high temperatures.

Source: Authors' own depiction.

Heat pumps can raise environmental heat to a temperature level that can be used for space heating.

Growth of heat pumps is strong but starting at a low level

Currently, half of all German homes are heated with natural gas, and only around three percent use heat pumps.[7] However, natural gas is increasingly losing importance in new buildings. For example, gas boilers were installed in only just under 27 percent in 2021. In contrast, heat pumps' importance has been continually increasing over the past years, and in 2021, they were installed in nearly 44 percent of new buildings.[8]

Heat pumps extract heat from the ground, underground water sources, or the air and use electricity to increase its temperature (Box 1). Together with building refurbishment to improve energy efficiency, the deployment of heat pumps is considered a key strategy in many future scenarios for reducing natural gas consumption and greenhouse gas emissions in the heating sector.[9] The potential use of other renewable heating technologies, such as biomass, remain limited due to resource potentials, while electricity-only heating systems are significantly less energy efficient than heat pumps. In urban areas, district heating from renewable energy sources can also play a role.

German policymakers have already identified heat pumps as a key technology for combating climate change. In 2021, there were around 1.4 million heat pumps in Germany.[10] The Federal Ministry for Economic Affairs and Climate Action's review of Germany's current climate action status targets a corridor of 4.1 to 6 million heat pumps by 2030, a figure derived from current climate action scenarios (Figure 1). This largely refers to heat pumps used for space heating and hot water in single- and two-family homes.[11]

Analyzing heat pump scenarios with an electricity sector model

The open-source electricity sector model DIETER[12] is used for the analysis. DIETER, which was developed at DIW Berlin, can be used to determine the power plant deployment and investment decisions that will meet electricity demand at the lowest possible cost for a given target year. The model version used in this analysis contains a detailed space heating module[13] and considers further sector coupling options (Box 2).

7 According to the BDEW, natural gas was used to heat 49.5 percent of all homes in residential buildings with heating in 2020. Cf. Arbeitsgemeinschaft Energiebilanzen, *Erdgasdaten 2021* (2022) (in German; available online).

8 Cf. Arbeitsgemeinschaft Energiebilanzen, *Erdgasdaten 2021*.

9 Stiftung Klimaneutralität et al., *Vergleich der „Big 5" Klimaneutralitätsszenarien* (2022) (in German; available online).

10 Cf. DIW Berlin's KoaVTracker (available online).

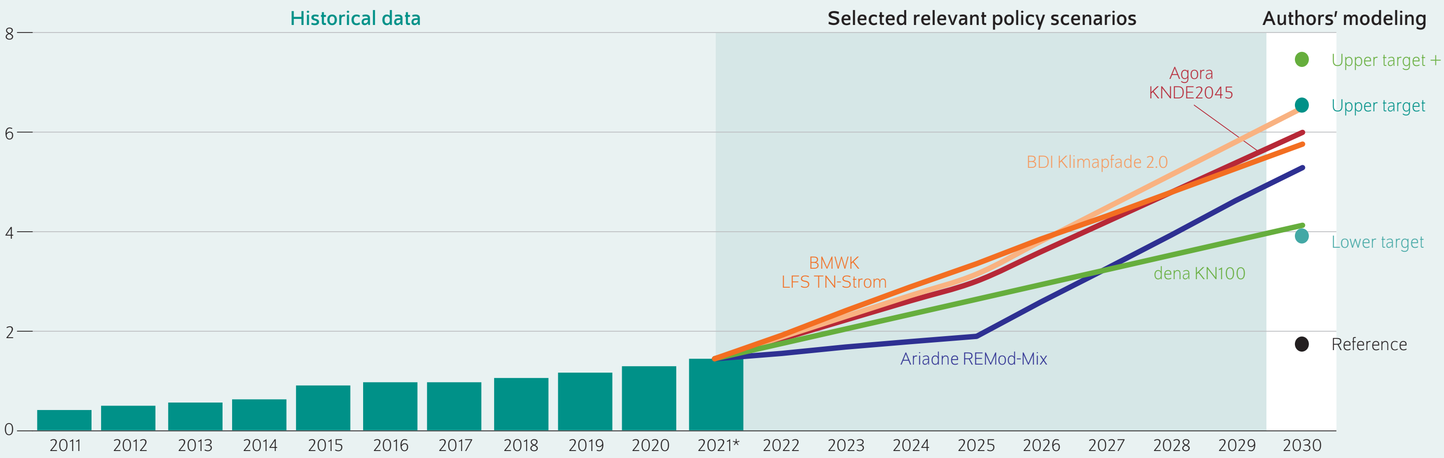
11 Moreover, high-temperature heat pumps could be used for process heating in the industrial sector. Cf. Silvia Maddedu et al., "The CO_2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat)," *Environmental Research Letters* 15 (2020) (available online).

12 Carlos Gaete et al., "DIETERpy: A Python framework for The Dispatch and Investment Evaluation Tool with Endogenous Renewables," *SoftwareX* 15 100784 (2021) (available online). See model documentation (available online).

13 Wolf-Peter Schill and Alexander Zerrahn, "Flexible electricity use for heating in markets with renewable energy," *Applied Energy* 266 114571 (2020) (available online).

Figure 1

Heat pump stock: historical data and different scenarios up to 2030
In millions of heat pumps



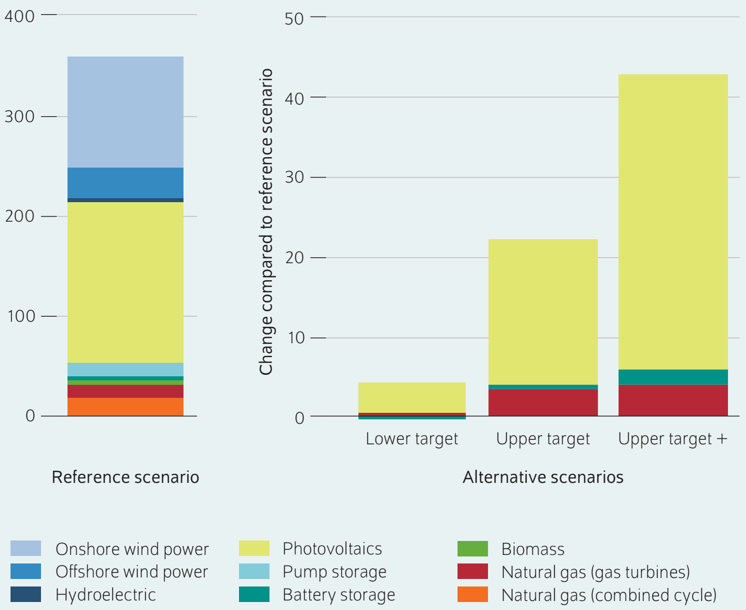
Note: Decentralized heat pumps for space heating and domestic hot water.

Sources: EurObserv'ER (up to 2020) (available online); Bundesverband Wärmepumpe for the 2021 estimated value (in German; available online); Agora Energiewende (in German; available online); Ariadne Project (in German; available online), BDI (in German; available online); BMWK (in German; available online); dena (in German; available online); 2022 to 2030 modeling.

The studied target scenarios cover a wide range of heat pump stocks.

Figure 2

Increase in installed power plant capacity due to additional heat pumps
In gigawatts



Note: The left column shows absolute values in the reference scenario. The right columns show the changes due to heat pumps.

Source: Authors' own calculations.

Heat pumps increase the required photovoltaic capacity by up to 37 gigawatts, or 23 percent, compared to the reference scenario.

The model is used to calculate various scenarios for 2030, which differ mainly in regard to heat pump stock. In the reference scenario, the historical shares of heat pumps in different building classes are extrapolated.[14] Under this assumption, there would be 1.7 million heat pumps in 2030, a little more than in 2022. In the *lower target* scenario, the number of heat pumps reaches 3.9 million. The additional heat pumps are installed exclusively in single- and two-family homes in those two building classes with the highest energy efficiency ratings. In the *upper target* scenario, there will be 6.5 million heat pumps in 2030. Unlike in the previous scenario, heat pumps are also installed in less energy-efficient single- and two-family homes. In the *upper target +* scenario, heat pumps are also installed in multi-family homes of various efficiency classes, which increases their total number to 7.5 million. In this third scenario, heat pumps provide nearly a quarter of total space heating and domestic hot water needs.

In accordance with the governing coalition's target, 80 percent of electricity consumption, including electric vehicles and electrolysis, comes from renewable energy sources in all scenarios. The additional electricity demand must be completely met by an increased amount of renewable energy sources over the course of one year in all scenarios.

14 Cf. Schill and Zerrahn, "Flexible electricity use for heating." Compared to the recent significant increase in the heat pump stock in Germany, this reference seems comparatively conservative.

Box 2

Open-source electricity sector model DIETER

The Dispatch and Investment Evaluation Tool with Endogenous Renewables (DIETER) is an open-source electricity sector model.[1] DIETER minimizes electricity sector costs and, depending on the application, other costs of flexibility and sector coupling options can be included. To realistically depict the variability of renewable energy or, for example, the use of storage facilities, all hours of a year are modeled.

Important input data for the model include time series of electricity, heat, and green hydrogen demand; a time series on the availability of variable renewable energy; cost assumptions; and constraints on investments in different technologies. The quantities determined in the model are the electricity sector costs, the optimal capacities of different technologies, and their hourly use.

Prices of 30 euros per MWh and of 130 euros per ton are assumed for natural gas and carbon emissions, respectively, for 2030. It is also assumed that fossil-fuel power plants are used at most within the limits permitted by the 2030 network development plan.[2] The modeling is carried out for Germany together with its neighboring countries and Italy. To reduce model complexity, electricity generation capacities are optimized only in Germany, while the power plant fleet abroad is fixed based on the Ten-Year Network Development Plan[3] (TYNDP) of the European Transmission System Operators.

The space heating sector is modeled for Germany using twelve different classes of residential buildings that are differentiated by size (single- and two-family as well as multi-family homes) and by age classes, for which different energy efficiencies are assumed.[4] The share of space heating to be covered by heat pumps is specified for the different scenarios and the use of heat pumps per hour is optimized. The assumed share of air source heat pumps of installed heat pumps is 75 percent for all building classes, while 25 percent of the heat pumps are ground source heat pumps. Installing air source heat pumps is easier and cheaper, but ground source heat pumps are more energy efficient. To ensure heat pumps may be operated flexibly in the short term, decentralized buffer storage is modeled for thermal energy with an assumed storage capacity for a maximum heat supply of two hours. The maximum heat supply is thereby varied in the sensitivity analyses. Central thermal energy storage facilities for seasonal storage are not considered.[5]

Furthermore, the model considers a fleet of 15 million electric cars, which require around 34 TWh of electricity per year. These are charged with a non-cost-optimized but relatively uniform time profile using the open-source tool *emobpy*.[6] In addition, there is a demand for 28 TWh of hydrogen in 2030, which must be generated by electrolysis, creating an additional electricity demand of just over 39 TWh. Due to assumed free hydrogen storage, the electrolyzers can be operated very flexibly.

1 There is a list of scientific papers with different DIETER model applications in the online documentation. The code and all input data used in this analysis are available online in a publicly accessible GitLab repository.

2 Here, the medium Scenario B of the network development plan is used. Cf. Bundesnetzagentur, *Bestätigung des Netzentwicklungsplans 2030 (Version 2019)* (2019) (in German; available online).

3 The Distributed Energy scenario from the TYNDP 2020 is used (available online).

4 Data on building stock from previous work was used. Cf. Wolf-Peter Schill et al., "Flexible Nutzung von Nachtspeicherheizungen kann ein kleiner Baustein für die Energiewende sein," *DIW Wochenbericht*, no. 46 (2018): 987–995 (in German; available online); Schill and Zerrahn, "Flexible electricity use for heating." A refurbishment rate of around two percent was assumed.

5 A figure depicting how heat pumps function can be found in the publicly accessible GitLab repository.

6 Carlos Gaete-Morales et al., "An open tool for creating battery-electric vehicle time series from empirical data, emobpy," *Scientific Data* 8, no. 152 (2021) (available online).

Electricity sector effects moderate under baseline assumptions

The model results described below are obtained under the baseline assumptions mentioned above and in Box 2, particularly for natural gas prices and thermal energy storage.

Heat pump expansion requires more photovoltaic capacity

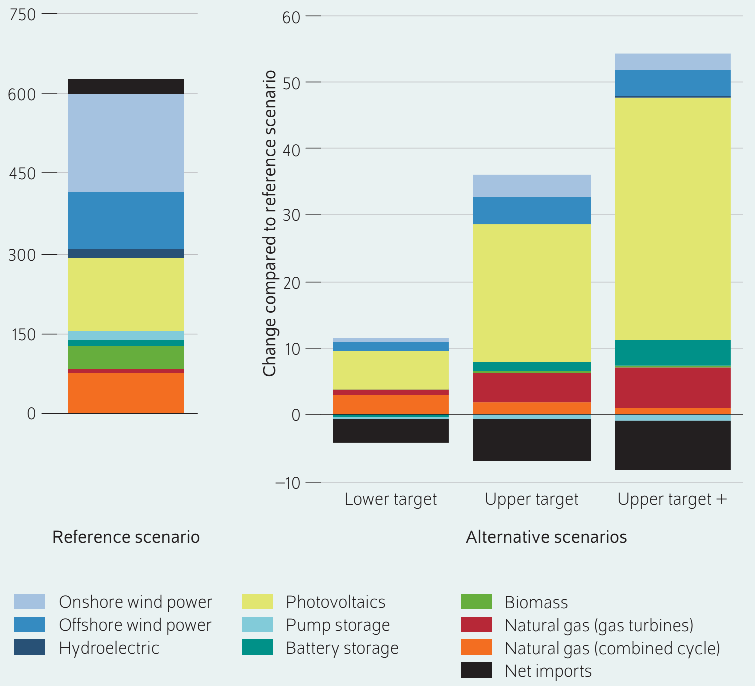
More heat pumps increase the electricity demand in Germany, especially during heating seasons. Power plant capacities must be expanded to completely meet additional demand with renewable energy sources (Figure 2). Since wind energy is already approaching the expansion limit of 110 gigawatts (GW, onshore wind power) and of 30 GW (offshore wind power) assumed for 2030 without any additional heat pumps, photovoltaics in particular must be expanded.[15] Compared to the reference scenario, an additional capacity of almost four GW and 18 GW (1.7 and 3.8 kilowatts per heat pump) is required in the *lower target* and *upper target* scenarios, respectively. The additional demand in the *upper target* scenario can be explained by, among other factors, the fact that the additional heat pumps in the *lower target* scenario can be partially powered by surplus electricity from renewable energy sources that is available in the reference scenario. In the *upper target* scenario, there are fewer surpluses; therefore, more generation capacity is needed. In the *upper target +* scenario, the additional capacity required is significantly higher: nearly 37 GW, or 6.3 kilowatts per heat

15 These limits are based on the German government's current expansion targets and take into account expansion barriers such as acceptance issues or lead times for land and project development.

Figure 3

Changes to annual electricity generation due to additional heat pumps

In terawatt hours



Note: The left column shows absolute values in the reference scenario. The right columns show the changes due to heat pumps.

Source: Authors' own calculations.

Electricity generation from photovoltaics increases significantly; generation from wind power, gas turbines, and battery storage grows less; and net imports sink.

pump, corresponding to an increase in photovoltaic capacity of around 23 percent compared to the reference scenario.[16] This rise is partially driven by an increase in the overall heat pump stock but also because heat pumps are installed in multi-family homes of varying efficiency classes in this scenario. These heat pumps heat larger spaces and thus have higher energy requirements compared to those in single- and two-family homes. Additionally, gas turbines and battery storage in the amount of four and two GW, respectively, are added in this scenario to help cover the additional peak loads caused by heat pumps during the heating season.[17] The optimal storage energy for battery storage systems also increases slightly, by about eight gigawatt hours (GWh) in the *upper target* scenario and by nearly 22 GWh in the *upper target* + scenario.

A similar picture emerges for electricity generation (Figure 3). The additional electricity demand in the heat pump scenarios will be met primarily by photovoltaics. Wind power is also used to a small extent, but not in the scenarios with fewer installed heat pumps. Electricity generation from open cycle gas turbines increases in the *upper target* and *upper target* + scenarios. At the same time, electricity imports, which amount to around 31 terawatt hours (TWh) in the reference scenario, fall by over 20 percent in some cases. In the *upper target* + scenario, electricity demand increases by just under nine percent, or 52 TWh compared to the reference scenario.

Electricity generation costs increase slightly

Based on the modeling results, the electricity generation costs, i.e., the sum of the fixed and variable costs of all electricity generation and storage technologies, can be calculated.[18] The costs increase with the number of heat pumps (Figure 4). Under baseline assumptions, the costs increase by around 0.6 and 2.6 billion euros per year in the *lower target* and *upper target* scenarios, respectively, compared to the reference scenario. This corresponds to 295 euros and 534 euros annually per heat pump. The cost increase is due to a higher demand for renewable electricity generation capacity. In the *upper target* + scenario, the annual electricity sector costs increase by almost four billion euros or 684 euros per heat pump. This increase is because heat pumps in multi-family homes heat significantly larger areas.

If the additional electricity sector costs are related to the additional space heating generated, the three scenarios produce relatively similar values. The value is lowest in the *lower target* scenario at around 3.07 cents per kilowatt-hour and highest in the *upper target* + scenario at 3.37 cents per kWh. The electricity sector costs for heating via heat pumps are relatively low in all scenarios because—in addition to the fact that the majority of the space heating provided by heat pumps is supplied from free environmental heat—cheap electricity is used. Analyzing data on electricity generation and consumption in an example winter week shows that heat pumps are operated flexibly to a certain extent, meaning they are oriented to wholesale prices. And even in winter, when only limited solar energy is available, the supply peaks of the midday hours can be used (Figure 5).

Sensitivity analysis: impact on electricity sector strongly depends on scenario assumptions

The impact of additional heat pumps on the electricity sector changes, sometimes significantly, when departing from the baseline assumptions described above. For example, if onshore wind energy can be expanded beyond the limit of 110 GW assumed for 2030, it will be used to a much greater extent. The additional electricity demand will then be met primarily by wind energy (Figure 6), as the seasonal profile of wind energy matches the electricity demand of heat

16 However, 161 GW of photovoltaic capacity in the reference scenario is significantly below the German government's target of 215 GW. In many climate neutrality scenarios, photovoltaic capacity increases even more significantly after 2030, cf. Ariadne, *Scenarios for climate neutrality: comparison of the "Big 5" studies* (2022) (in German; available online).

17 Because heat pumps are operated flexibly, the hourly peak residual load increases by only around four gigawatt, even in the *upper target* + scenario.

18 Excluding investment costs for heat pumps, as these are fixed in the scenarios (Box 2). These are long-term costs of electricity generation, also referred to as electricity sector costs.

pumps better than photovoltaics.[19] However, the increase in electricity sector costs caused by heat pumps is almost as high in this scenario as it would be if photovoltaic capacities were expanded. Accordingly, heat pumps can well be combined with an expansion of solar power, in case wind power expansion potentials are limited.

In another sensitivity analysis, a renewable energy drought week is considered, an entire week in February (i.e., during the heating season) during which no solar or wind electricity can be used. In such a scenario, photovoltaics must be expanded to a significantly greater extent than under baseline assumptions. In the *upper target* + scenario, this is accompanied by a greater expansion of battery and long-duration electricity storage of around four GW (discharge capacity) and just under 1.5 TWh (storage energy capacity for long-duration storage). Furthermore, lignite generation capacity increases by around four GW, but this capacity is hardly used over the course of the year. Due to these extra required investments, the additional electricity sector costs caused by heat pumps are slightly higher compared to the reference scenario. However, the electricity generation costs stay low even in a renewable energy drought scenario, as Germany is partly benefiting from electricity generation capacities in neighboring countries. Furthermore, another sensitivity analysis shows that the additional electricity storage need is almost zero when the thermal energy storage capacity coupled to heat pumps increases from two hours (baseline assumption) to twelve hours.

In a scenario with higher natural gas prices (60 instead of 30 euros per megawatt hour, MWh), significantly larger investments in photovoltaics and, to a lesser extent, in stationary battery storage, are optimal compared to under the baseline assumptions. This applies whether or not coal-fired power plants are still operational by 2030.

When Germany is modeled as an island without any electricity exchange with its neighboring countries, the additional electricity generation capacity required due to heat pumps is much higher than under the baseline assumptions. Investments in photovoltaics and battery storage increase in particular. This finding illustrates the benefits of a European electricity exchange.

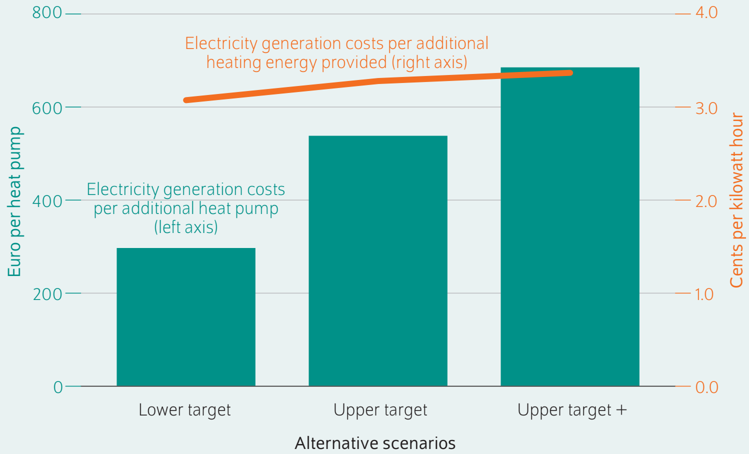
When considering costs saved on natural gas heating, overall economic costs may decrease

In the electricity sector model analysis, the focus lies on the effects of heat pump expansion on the electricity sector and on electricity generation costs. Yet overall cost effects can also be estimated by supplementing the modeling results with the investment costs of heat pumps as well as the costs saved on natural gas by replacing gas heating systems. For simplicity, it is assumed that every additional heat pump replaces a gas heating system. The additional investment costs for heat pumps compared to gas heating systems are subject to uncertainty, as they also depend on the size of the system and the type of heat pump.[20]

Figure 4

Increase in electricity generation costs due to additional heat pumps

In euro per heat pump (left axis) or in cents per kilowatt hours of heating energy (right axis)



Note: The electricity generation costs contain the fixed and variable costs of all electricity generation and storage technologies used.

Source: Authors' own calculations.

Electricity generation costs rise moderately as heat pump use increases.

Compared to the reference scenario, all three target scenarios result in slightly higher total annual costs of between 80 and 380 million euros at a natural gas import price of 30 euros per MWh and a carbon price of 130 euros per ton.[21] Assuming a higher gas price of 60 euros per MWh, the calculated total costs are lower in all target scenarios because the costs saved on natural gas and emissions outweigh the additional investment and electricity sector costs. Under these assumptions, nearly 3.6 billion euros per year could be saved in the most ambitious expansion scenario.

Thus, from an overall economic point of view, the accelerated expansion of heat pumps is unproblematic; with long-term high natural gas prices, it is even significantly advantageous. However, only the costs of supplying electricity and heat are included in the analysis and, apart from carbon costs, no taxes, duties, or surcharges are considered. Since these are not the same for electricity and natural gas, the cost comparison between a heat pump and a natural gas

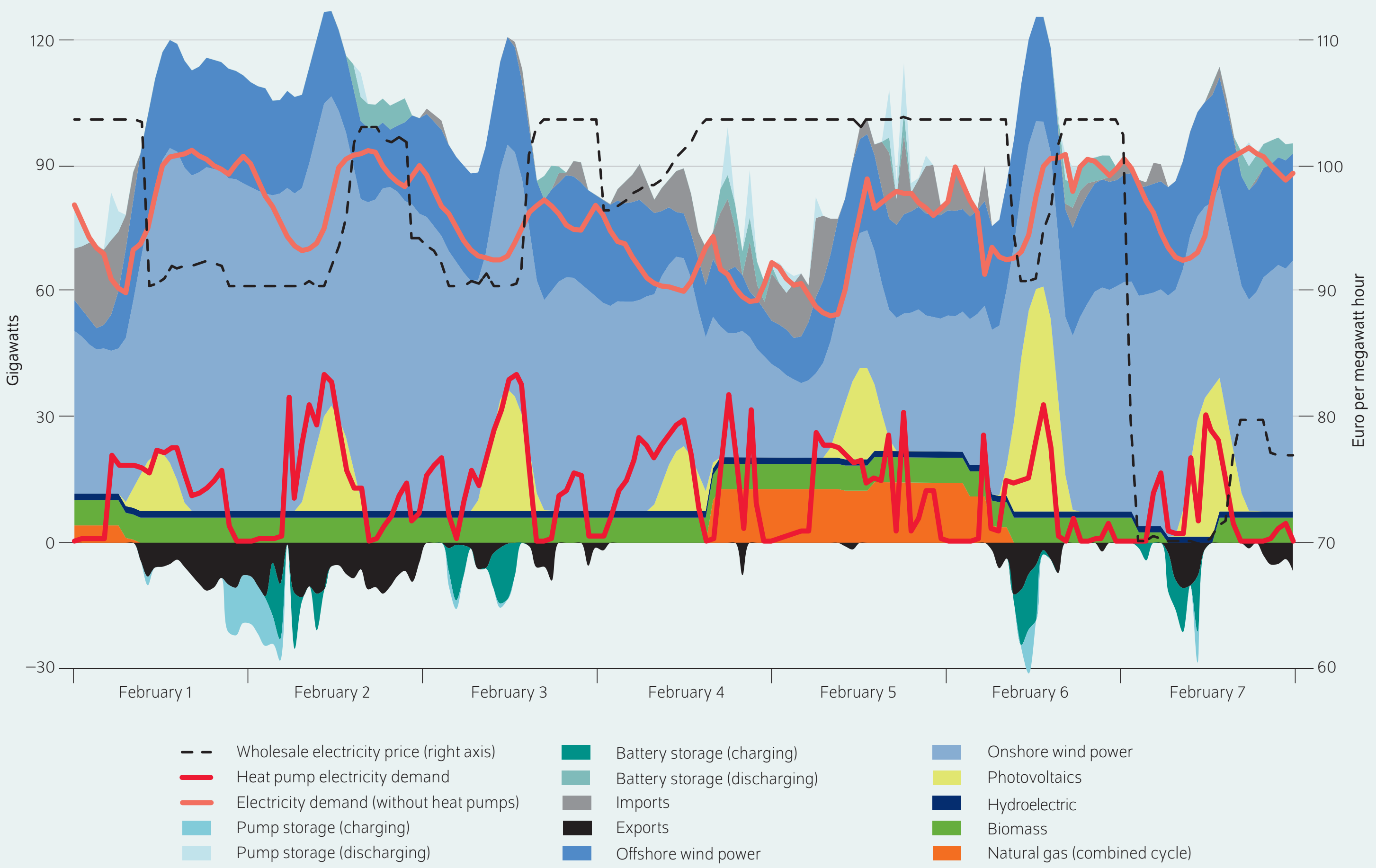
19 Cf. similar findings in Oliver Ruhnau, Lion Hirth, and Aaron Praktiknjo, "Heating with wind: Economics of heat pumps and variable renewables," *Applied Energy* 92 104967 (2020).

20 It is assumed that only the additional heat pump costs are relevant to natural gas heating systems. For more on investment costs, cf. Marta Victoria et al., "Early decarbonisation of the European energy system pays off," *Nature Communications* 11 (2020) (available online). The calculations are available as a spreadsheet in the GitLab repository of this analysis.

21 These assumptions are also used in the electricity sector (Box 2).

Figure 5

Electricity generation and demand as well as wholesale prices in an example winter week
In gigawatts (left axis) and in euro per megawatt hour (right axis)



Note: The figure shows the first week in February in the *upper target +* scenario.

Source: Authors' own calculations.

Heat pumps that base their operation on wholesale prices use the generation peaks of renewable energy sources as well as hours with low prices as much as possible.

heating system may be different from an individual household's perspective.[22]

Due to the increased use of heat pumps, natural gas consumption in 2030 is between 16 TWh (*lower target*) and 113 TWh (*upper target +*) lower than in the reference scenario. This corresponds to two and 15 percent of German natural gas imports from Russia in 2021, respectively.

Conclusion: in the power sector, little standing in the way of a heat pump transition

Increasing the use of heat pumps results in more electricity consumption: If almost six million heat pumps are added by 2030, electricity consumption will increase by nearly nine percent. Thus, electricity generation from renewable energy sources must be expanded to meet this demand, which can be achieved by increasing photovoltaic capacity by up to 23 percent. Taking into account the costs saved on natural gas, the overall economic costs hardly increase—or even decrease significantly if the price of natural gas remains high. At the same time, 15 percent of current imports of natural gas will be saved.

A combination of heat pumps and wind energy would be slightly cheaper as its seasonal profile fits well with the heating season. In general, the modeled effects on other technologies in the electricity sector, especially on electricity storage, are moderate. This also applies under alternative assumptions or during an especially extreme weather period. Reasons for this include the possibilities to use heat pumps flexibly as well as balancing effects in the interconnected power grid. In terms of the impact on the electricity sector, there are thus no significant obstacles to accelerating the

22 For more detailed estimates cf., for example, BDEW, *Der BDEW-Heizkostenvergleich* (in German; available online); Jens Clausen and Simon Hinterholzer, *Wärmepumpenanlagen: Technologie, Wirtschaftlichkeit, Diffusionsfaktoren* (Borderstep Institut: 2022) (in German; available online).

expansion of heat pumps. In fact, in terms of overall costs, it could even be significantly beneficial.

The focus of this analysis is on the generation costs for electricity and heating. The electricity tariffs faced by end consumers, however, include taxes, duties, and surcharges. Designing the tariffs in such a way that they do not inhibit a prudent and temporally flexible use of heat pumps remains a very important task for policymakers.[23] In addition to the abolition of the EEG surcharge,[24] further surcharges on electricity for heat pumps could be reduced.

The planned amendment to the *Gebäudeenergiegesetz* (Buildings Energy Act) can provide further positive impetus for heat pump expansion. In particular, the upcoming change requiring 65 percent renewable heat in newly installed heating systems as early as 2024 is likely to amount to a *de facto* heat pump mandate in many cases.[25] Moreover, policymakers should take measures to significantly accelerate heat pump expansion. In particular, such measures can focus on expanding the production capacities for heat pumps, providing specialist training, establishing regulatory measures, providing information and coordination offers for owners and tenants, and, if necessary, developing further financial support measures or financing models. In addition, there are further aspects not investigated here, such as hybrid heat pump technologies, the integration of heat pumps into local and district heating networks, and increasing the energy efficiency in existing buildings. With a coordinated package of measures, an Apollo-style program for the transition to heat pumps could be started—a program that would significantly reduce the dependency on natural gas imports in the medium and long term, make a significant contribution to combating climate change, and provide important impetus for industrial policy.

23 Cf. for example Andrea Dertinger and Wolf-Peter Schill, "Ansätze zur Umgestaltung von Abgaben und Umlagen auf Strom sowie Heiz- und Kraftstoffe," *DIW Roundup* 127 (2019) (in German; available online).

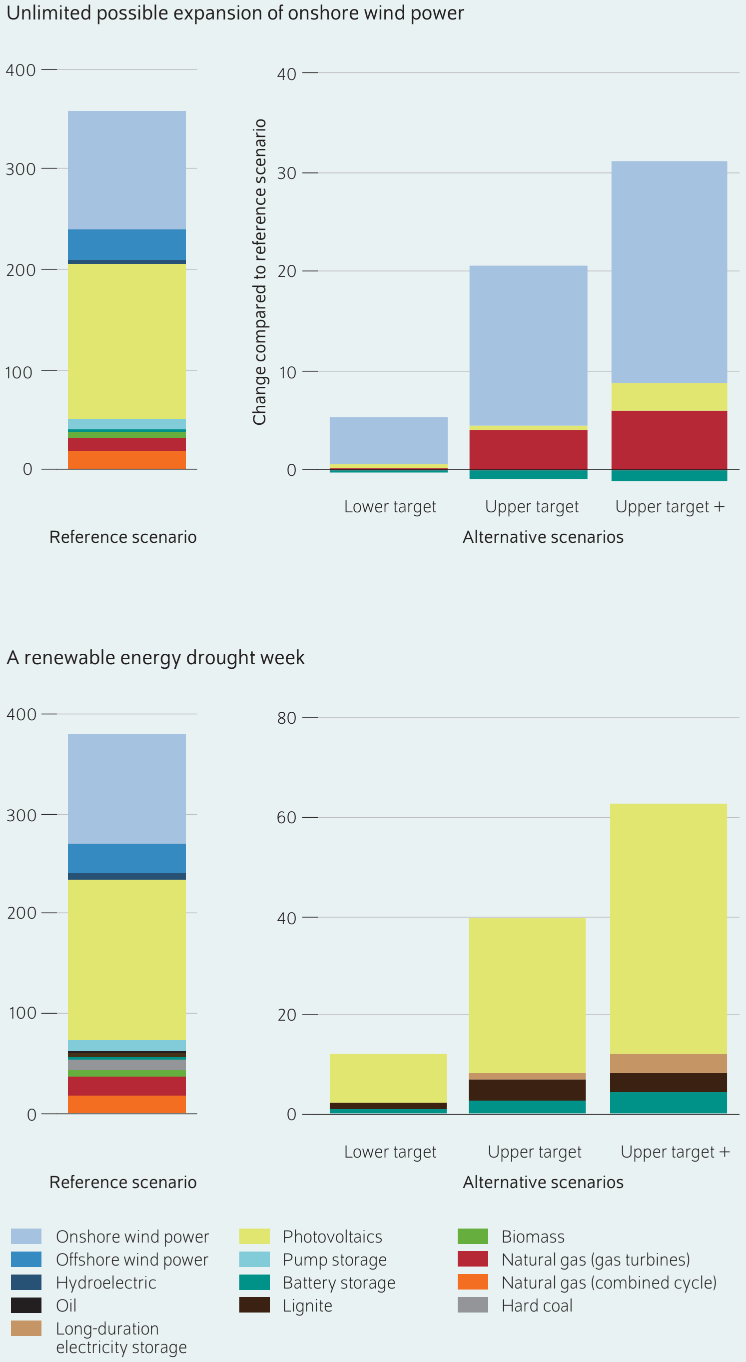
24 Cf. Bundesministerium für Wirtschaft und Klimaschutz, *Überblickspapier Osterpaket* (2022) (in German; available online).

25 Draft wording, amendment to the Buildings Energy Act (2022) (in German; available online).

Figure 6

Increase in installed power plant capacity due to additional heat pumps under alternative assumptions

In gigawatts



Note: The left columns show absolute values in the reference scenario. The right-side columns show the changes due to heat pumps.

Source: Authors' own calculations.

If onshore wind power can be expanded without restrictions, it is expanded significantly to meet the electricity demand of the additional heat pumps.

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