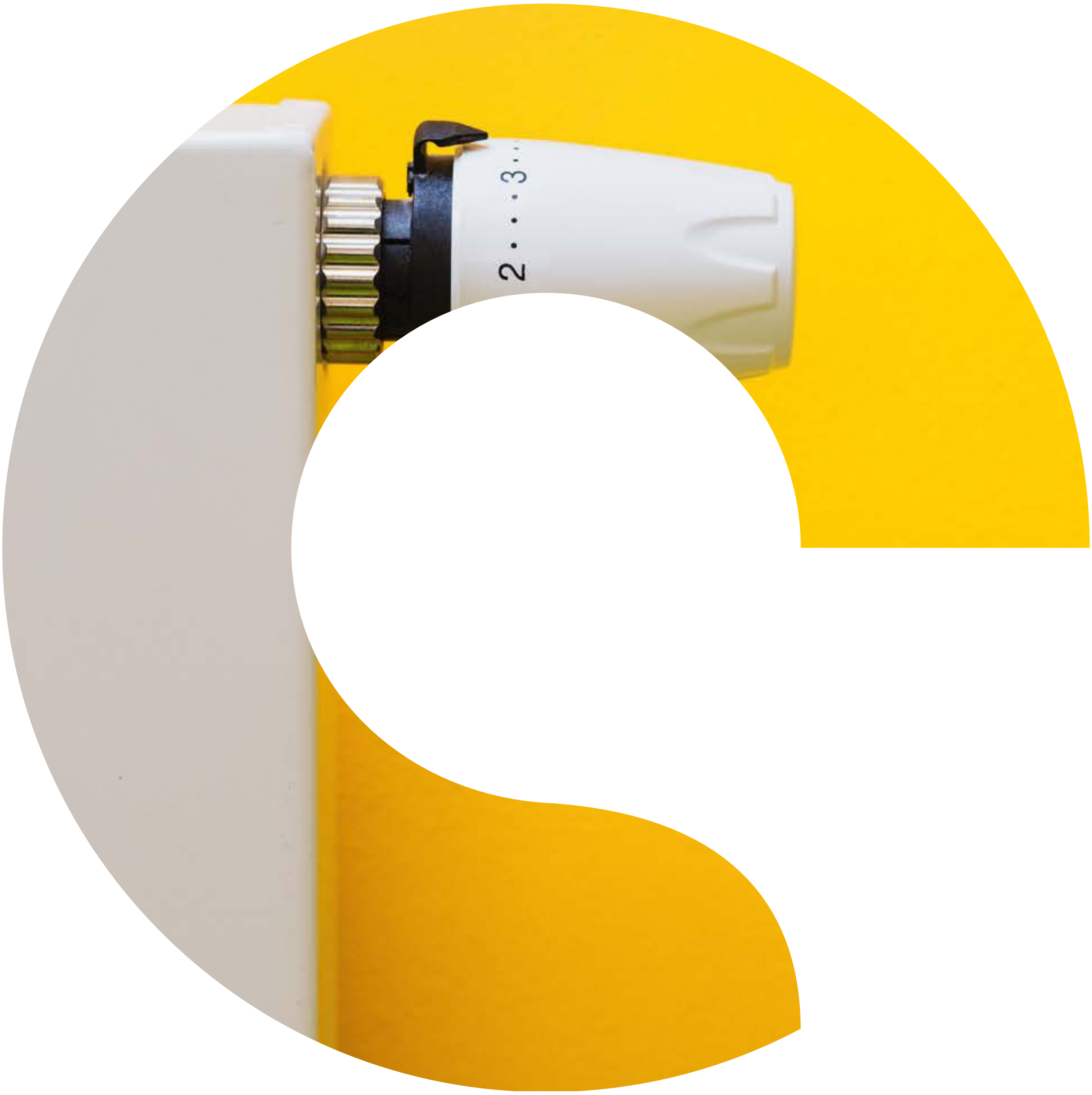
Heat Transition 2030

Key technologies for reaching the intermediate and long-term climate targets in the building sector

SUMMARY

Agora Energiewende



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IMPRINT

SUMMARY OF STUDY

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Preface

Dear readers,

Among the targets set by the German government's 2050 climate protection plan is one reserved specifically for the building sector: a reduction of annual greenhouse gas emissions to between 70 and 72 million tons of CO_2 by 2030. Reaching this target will take a *Wärmewende*, a fundamental transformation in building heating technology and insulation. Such a transformation will have to rely on three cornerstones: energy efficiency, low-carbon district heating, and local renewable energy sources. But it is unclear how expansive these measures must be if Germany is to reach its environmental goals, especially given the ambitious targets for 2050.

To answer this question, we commissioned the Fraunhofer Institutes for Wind Energy and Energy System Technology (IWES) and for Building Physics (IBP) to identify the minimum levels of key technologies and approaches needed for decarbonisation. Their findings show that Germany must significantly boost efforts in green retrofitting, proliferating heat pumps, and expanding district heating to put the building sector on the right track.

I hope you find the report as stimulating a read as I do.

Sincerely, Patrick Graichen
Director, Agora Energiewende

Findings at a glance:

1. **The heating sector needs to phase out oil: A cost-efficient, climate friendly energy mix for building heating would most likely consist of 40 per cent natural gas, 25 per cent heat pumps, and 20 per cent district heating – with little to no oil.** In this scenario, the importance of natural gas remains roughly the same as today, while oil heating is almost entirely replaced by heat pumps. District heating is another key factor. By 2030, district heating will primarily draw on heat from CHP plants, but it will increasingly rely on solar thermal energy, deep geothermal energy, industrial waste heat, and large-scale heat pumps as well.

2. **Efficiency is decisive: To meet 2030 targets, energy use for building heating must decline by 25 per cent relative to 2015 levels.** Energy efficiency is a pillar of decarbonisation because it makes climate protection affordable. Improving energy use efficiency in buildings requires a green retrofit rate of 2 per cent and a high retrofit depth. But current trends in building modernisation fall far short of these targets.

3. **The heat pump gap: Based on current trends, some 2 million heat pumps will be installed by 2030 – but 5 to 6 million are needed.** To close this gap, heat pumps must be installed early on not only in new buildings but also in existing buildings, for example as bivalent systems with fossil fuel-fired boilers for peak demand. If heat pumps can be flexibly managed and existing storage heaters replaced with efficient heating units by 2030, the 5 to 6 million heat pumps will affect only a slight rise on peak demand that thermal power plants must cover.

4. **Renewable electricity for heat pumps: By 2030, renewable energy must comprise at least 60 per cent of gross power consumption.** To reach the 2030 climate protection target, additional electricity consumption in the heating and traffic sector must be covered by CO_2-free energy sources. But the new renewable energy capacities stipulated in EEG 2017 will not suffice to do so.

Summary

Where must we be in 2030 to reach energy transition targets for 2050?

Germany is still a long way from reducing its greenhouse gas emissions by 80 percent to 95 percent relative to 1990 levels, as required by its 2050 targets. And exclusive focus on the year 2050 makes it more likely that politicians will drag their feet taking the necessary measures. Until now, Germany's intermediate climate targets – for 2030 – have primarily focused on reducing total greenhouse gases by 55 percent relative to 1990 levels and reducing greenhouse gases not covered by the EU Emissions trading System (EU ETS) by 38 percent relative to 2005 levels.[1]

This study provides robust "guardrails" for 2030 that develop a clearer framework for important target figures and for initiating the necessary measures within the 2030 timeframe. It focuses on the minimum penetration levels of key technologies at the junction of the electricity and heating sectors that must be reached by 2030. These technologies are centred on building efficiency, heating networks and heat pumps. The last two will receive in-depth analysis in this study.

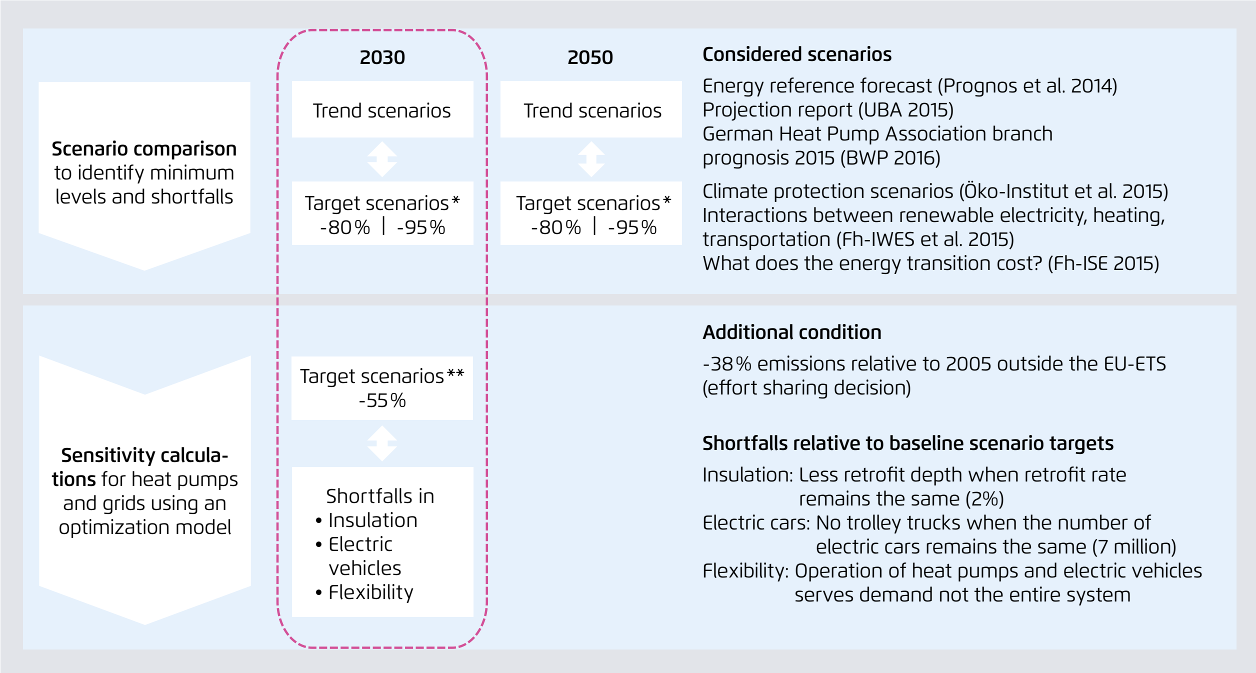
To determine the minimum levels, current target scenarios are compared for a greenhouse gas reduction of 80 percent to 95 percent (Figure 1). This results in ranges for the required 2030 and 2050 trajectories, which are then measured against projected trends to identify shortfalls. Especially relevant here are possible path dependences. That is to say, what must be accomplished by 2030 so that Germany still has a chance of reducing its greenhouse gas emissions by 95 percent come 2050?

In a second step, sensitivities are calculated for 2030 using an energy system optimization model. These sensitivities are used to analyse whether a minimum reduction in greenhouse gases of 55 percent can be reached by 2030 should underperformance in key technologies occur, requiring supplementation by measures in other areas. The baseline scenario consists of a green retrofit rate of 2 percent given a high green retrofit depth, seven million electric cars, the use of trolley trucks and the deployment of heat pumps and electric cars in a way that benefits the energy system as a whole.[2] The parameters varied in the sensitivity calculations concern building insulation, the penetration of electric vehicles and the flexibility of heat pumps and electric cars and trucks. An additional condition is a 38 percent reduction by 2030 of greenhouse gas emissions in the areas of transport, agriculture and the decentralised supply of heating energy, none of which are subject to EU ETS.

1 As of late 2016, sector targets were added to the 2050 climate protection plan. This study was unable to take into account these targets (Bundesregierung 2016).

2 Electric trucks (both battery-powered trucks andplug-in hybrid electric trucks) consume 24 percent of total energy used by all trucks.

Method – comparison of scenarios and sensitivity calculations Figure 1



* Greenhouse gas emissions in 2050 relative to 1990 levels ** Total greenhouse gas emissions in 2030 relative to 1990 levels
Source: Authors' own illustration

A climate-neutral building stock in 2050 must rely on efficiency, distributed renewable energy, and decarbonised heat networks

Current political discussions in Germany about building heating focus on the federal government's strategy for enhancing energy efficiency in buildings.[3] These discussions seek to assess the potential of renewables and usage-cutting measures to find feasible solutions for making building stock practically climate neutral. Specifically, the goal is to reduce non-renewable primary energy consumption by some 80 percent by 2050 relative to 2008 levels. So far, policymakers have determined that heat end energy consumptions in households and businesses can be sunk by 40 percent to 60 percent on average, though any more than this would be very difficult given current technological restrictions. The government has provided "realistic" potentials for three nearby renewable energy sources: ambient heat, solar thermal and biomass. If these are expanded by the potentials recently estimated for ambient heat[4] and heat pump electricity, the range of heat generated from nearby renewable energy is 197 to 447 TWh per year.[5] The remaining heat consumption needs must be achieved by decarbonised heat networks. All three pillars of greenhouse gas reduction in the building heating sector are illustrated in Figure 2 using the example of a 40 percent reduction of energy consumption for building heating. Some inaccuracy here is unavoidable, since a portion of nearby renewable

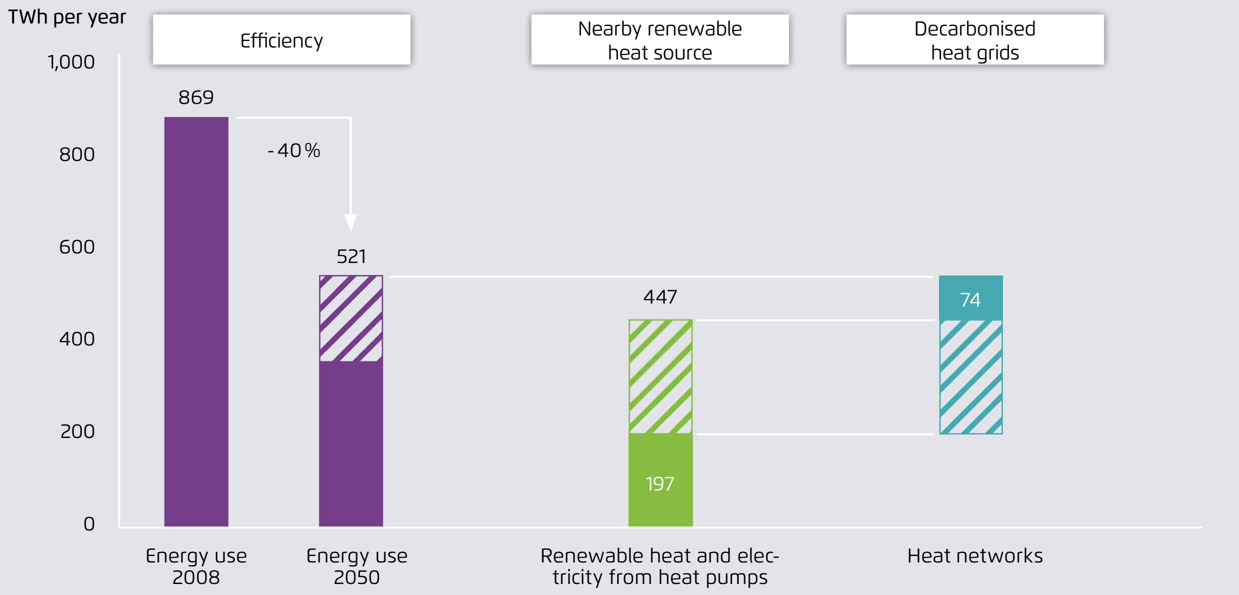
3 These statements primarily refer to the background paper (Prognos, ifeu, IWU 2015) on energy efficiency strategy in buildings (BMWi 2015).

4 See ifeu (2016)

5 The breakdown of the yearly individual energy ranges are as follows: solar thermal: 53–69 TWh; biomass: 69–139 TWh; ambient heat: 58–186 TWh. In addition, electricity generated from heat pumps is projected to be 17–53 TWh per year.

Decarbonisation options with a 40 percent reduction of final energy use for building heat in TWh per year

Figure 2



The hatched areas indicate the range of potentials for efficiency and renewable energy. A portion of nearby renewable heat sources can also be merged together as part of small-scale distributed heat networks. Calculations based on Prognos, ifeu, IWU (2015), ifeu (2016) and authors' assumptions about electricity from heat pumps.

heat sources can be merged together as part of small-scale distributed heating systems, what in German is known as *Nahwärme.*

Current developments in building heat efficiency and heat networks are not enough

Energy efficiency is the pillar of decarbonisation. The key for reaching climate policy targets lies in the green retrofit of building stock. The compared target scenarios almost all assume a strong decline of energy for heat by some 40 percent by 2030 and by 60 percent by 2050 relative to 2008 levels (temperature adjusted). But current developments in energy use for heat will fall short of these targets, especially if a 95 percent reduction of greenhouse gases relative to 2008 levels is to be reached.

Heat grids are mostly useful in densely populated areas, where the deployment of decentralized renewable energy sources is limited. In the scenario comparison, the expansion of district heating networks (Fernwärme) from around 10 percent[6] of final energy use today to around 23 percent of final energy use by 2050 can be noticeable improved (Figure 3), but it is nevertheless limited, since most of the heat market is determined by decentralized boilers in all scenarios. In the -80 percent scenarios, somewhat larger ranges are possible for the necessary heat network share. In the -95 percent scenarios, however, the leeway is considerably smaller. By 2030 the share of heat networks in the final energy needs of buildings must increase considerably if a 95 percent reduction of greenhouse gas emissions relative to 1990 levels is to be reached by 2050, for a leap from low levels in 2030 to high levels in 2050 is not realistic.

6 This does not include biogenic distributed heating systems in rural areas.

For the long-term decarbonisation of heat grids, it is essential that temperatures be reduced and deep geothermal energy, large-scale solar thermal installations and/or the use of ambient heat/waste heat utilization (drain water, industry, rivers, sewage water, etc.) with large-scale heat pumps be used. The sensitivity calculations for 2030 indicate that heat networks need to be expanded to between 15 percent and 21 percent of final building energy use.[7] What seems most sensible is to combine these with large scale solar thermal energy, though this depends strongly on local conditions. (More research is needed.) Large-scale heat pump systems are profitable today for systems in which heating and cooling occur at the same time, and they have a large potential for heat networks. Especially if higher source temperatures and, by extension, higher efficiency levels are possible, these systems become economically viable sooner. There are several projects today in the area of deep geothermal energy. By contrast, industry waste heat has seen extremely limited use.

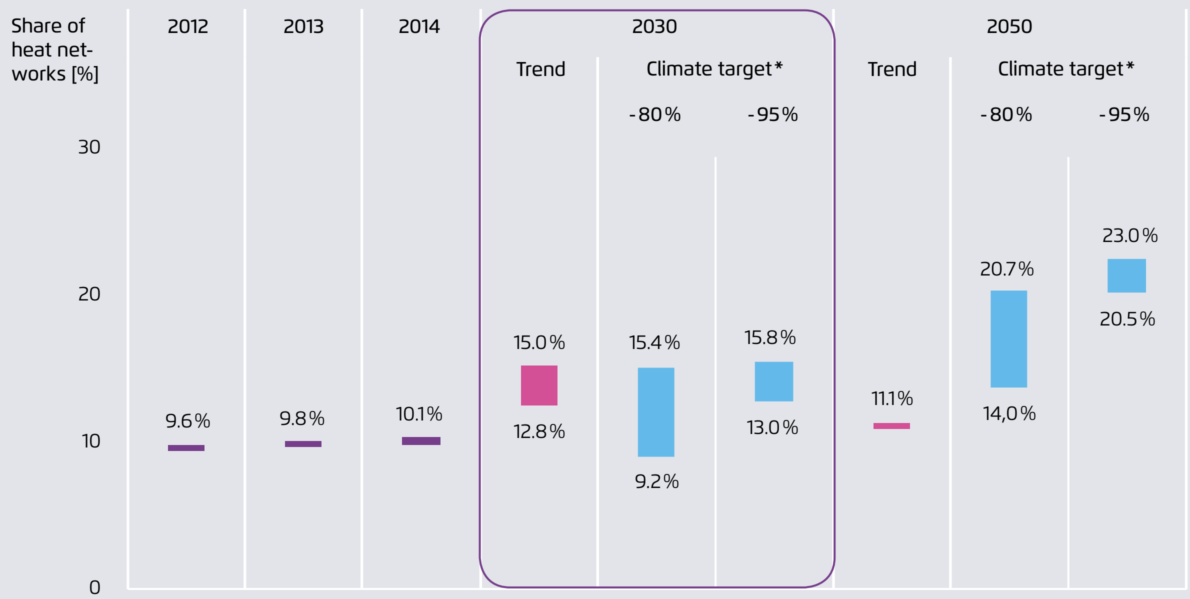
7 Here, higher values are reached than in the 2030 scenario comparison because the greater number of added CHP plants in heat networks compensates for shortfalls in specific key technologies.

By 2030 Germany requires five to six million heat pumps to reduce greenhouse gases by 55 percent in 2030 and by at least 80 percent by 2050.

In all target scenarios, a decentralized heat pump for building supply is a key technology with a high to very high level of market penetration. By comparison, the trend scenarios show the obstacles in the current regulatory framework. This results in a shortfall of around 3 to 4 million heat pumps between trend scenario levels and the needed target value of at 5 to 6 million heat pumps (Figure 4).[8]

8 The target value of five million heat pumps results

Share of heat grids in the final energy use of buildings in scenario comparison (percent) Figure 3



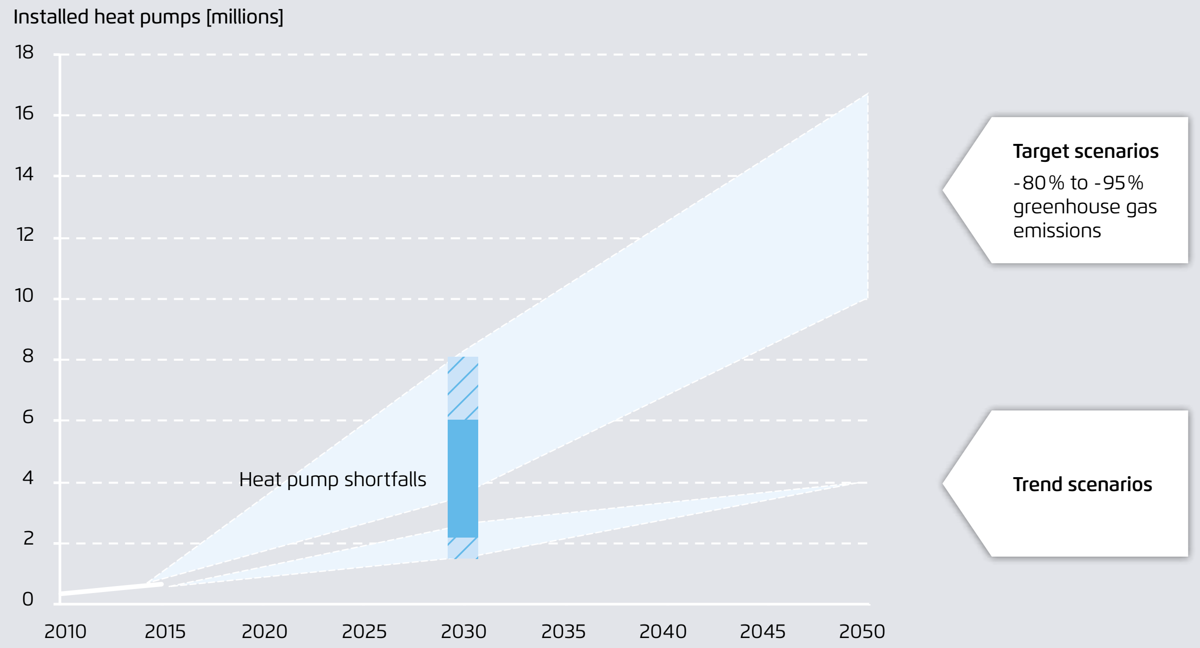
* The climate target of -80 percent also includes scenarios with 83 percent and 85 percent reductions of greenhouse gases.
Prognos et al. (2014); Fh-ISE (2015); Fh-IWES et al (2015); Öko-Institut et al. (2015); UBA/BMUB (2015)

In the trend scenarios, heat pump sales per year rise by around 60 percent relative to today's levels. To reach the average target scenarios, sales must increase fivefold. Here, a distinction must be made between new construction and existing building stock. In new construction, primary energy needs (fossils) must be met according to energy saving regulations, so that heat pumps play an important role despite higher electricity costs in the market since 2016. In existing building stock, the share of heat pumps in all heating systems currently amounts to only 2 percent. As a rule, portions of the heat pump market can also be covered by small-scale distributed heating systems for supplying smaller quarters (through the use of ground probe fields, say). Here, the lines between decentralized and grid-based heat pumps are blurry.

from the sensitivity calculations for 2030 described below; the value of six million heat pumps from the climate target of -95 percent by 2050.

In view of the current inertia and restrictions for changing existing heating systems, it is impossible to switch from an 80 percent reduction to a 95 percent reduction of greenhouse gases at just any point of time. The dotted lines in Figure 5 show the window of opportunity for a switch. If no heating systems are replaced before the end of their mechanical life span – a measure that leads to their devaluation – an ambitious minimum level of heat pumps for 2030 is needed. A comparison of the example scenarios ISWV-83 and ISWV-95 shows that for 2030 the upper long-term scenario path must be targeted, which equals around 8.1 million heat pumps. A similar consideration of the climate protection scenarios KSz 80 and KSz 95 results in around 5.8 million heat pumps for 2030. Overall, the minimum 2030 level needed for a 95 percent reduction of greenhouse gases by 2050 is around 6 to 8 million heat pumps.

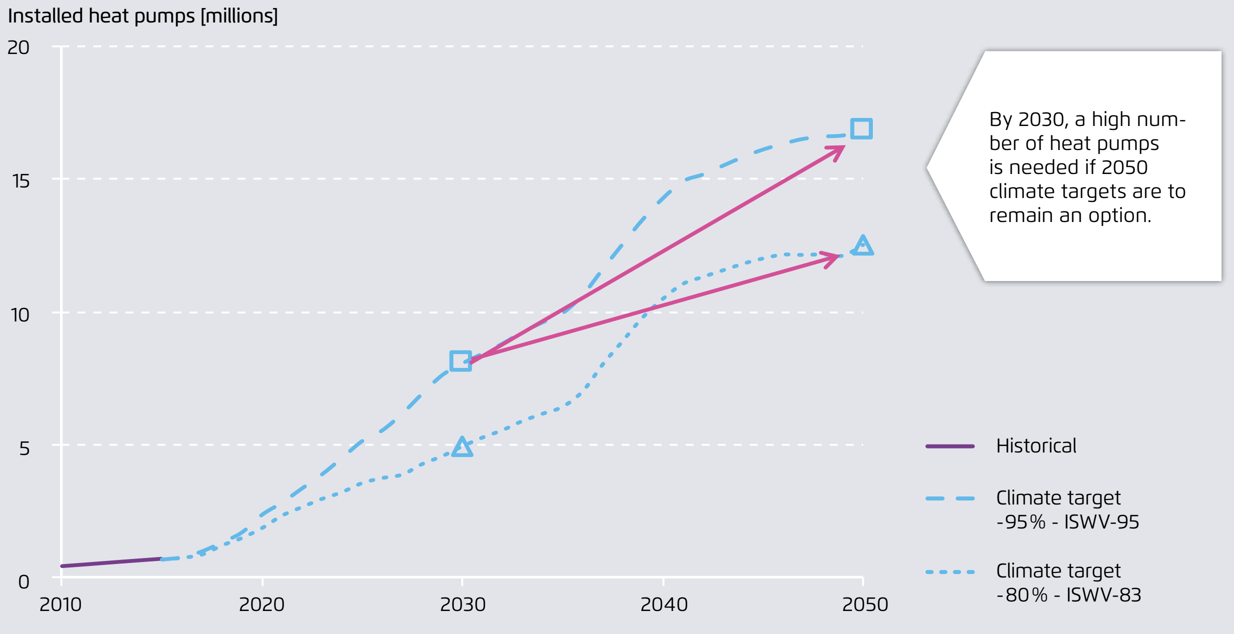
Number of heat pumps in scenario comparison in millions and shortfalls in heat pumps — Figure 4



A portion of heat pumps in individual buildings can be merged as part of small-scale distributed heat networks.
BWP (2016); Prognos et al. (2014); Fh-ISE (2015); Fh-IWES et al (2015); Öko-Institut et al. (2015); UBA/BMUB (2015)

Number of heat pumps in the ISWV scenarios in millions

Figure 5



Note: The relatively high level in the climate protection scenarios (KSz 95) requires around 6 million heat pumps in 2030 to reach some 14 million heat pumps by 2050 (Öko-Institut et al. 2015).

Fh-IWES et al. (2015)

Decarbonisation using heat pumps can help compensate for shortfalls in building insulation and electric cars by 2030

Whether a 55 percent reduction of greenhouse gas emissions relative to 1990 levels and a 38 percent reduction in emissions outside the purview of the EU-ETS relative to 2005 levels is feasible depends on the contributions from individual sectors. In the heating sector, building insulation is decisive; in the transportation sector, it is electric vehicles. In a baseline scenario for 2030, we assume an increase in the green retrofit rate to 2 percent, a high green retrofit depth and a strong penetration of electric vehicles – 7 million electric cars by 2030 and an early introduction of hybrid trolley trucks. Moreover, the new electricity consumers provide flexibility because heat pumps are installed with heat storage and electric cars are charged in a way that is advantageous for the power system as a whole.

To classify the following results, we must first note that a faster proliferation of heat pumps is part of a heating mix that develops dynamically over time against the backdrop of decarbonisation targets. For the relevant target year of 2030, decentralized gas-fired boilers will be added in considerable quantities alongside the heat pumps in the calculated base scenario, because the optimisation algorithm tries to identify the most affordable solutions given greenhouse gas emission targets.[9]

In the baseline calculation ("Basis KK") around 4 million installed heat pumps are needed in 2030 to reach the emission targets (Figure 6). If one assumes a **low green retrofit depth ("Dämm(-)"),** heat consumption increases. The decarbonisation of decentralized heat supply is a particular challenge in this scenario. Existing boilers, whose emission levels are

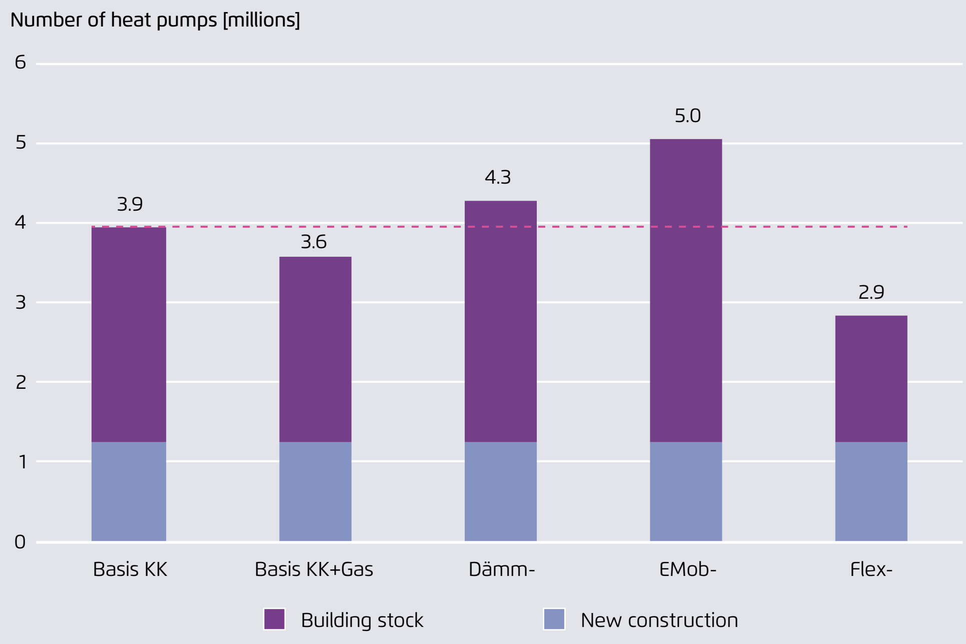
9 For more details, see the next section on the 2030 building heat mix.

fixed, limit the available CO_2 budget, especially in the non-ETS area, while high heat demand can be covered by adding more boilers. On the one hand, this pressure will increase district heating projects that shift emissions from decentralized facilities outside the purview of EU-ETS to the ETS area. On the other hand, decarbonisation will be increasingly be carried out via heat pumps, especially bivalent air source heat pumps (in combination with gas-fired boilers during peak demand). This will increase the number of heat pumps to over 4 million. In response, the number of newly installed gas-fired boilers will decrease.

In the case of a **lower penetration of electric vehicles ("EMob(-)"),** the CO_2 budget outside the EU-ETS area will be restricted further. As a result, building heat

Sensitivity calculation with number of installed heat pumps in 2030 together with output and energy for heat pumps*

Figure 6



	Baseline scenarios		Sensitivities		
Variations for 2030	**Basis KK**	**Basis KK+Gas**	**Dämm-**	**EMob-**	**Flex-**
Assumptions	Coal consensus path (18.5 GW from coal-fired power plants)	Coal consensus path + switch from coal to gas	Lower insulation standard	Lower share of electric car use	No decentralized flexibility in heat pumps and electric cars**
Highest demand [GW]	17	11	20	21	10
Energy consumed [TWh]	36	22	42	43	16

* Heat pumps include ground source heat pumps, monovalent air source heat pumps and hybrid air source heat pumps
** Electric car charging does not benefit the system, trolley truck hybrids cannot be switched to hybrid mode and heat pumps lack heat accumulators

supply will need more decarbonisation. Far fewer gas-fired boilers will be added, and instead more district heating and increasingly efficient heat pumps will be deployed, that is, the share of ground source heat pumps will increase. The number of heat pumps will rise to 5 million in 2030 to ensure that targets for emissions outside the EU-ETS are adhered to.

In the event that heat pumps and electric vehicles **lack flexibility ("Flex(-)"),** the number of heat pumps will decline to just under 3 million. In this way, the optimisation model avoids inflexible consumers. Instead, new district heating solutions in the model will shift emissions from the non-EU- ETS areas into the EU-ETS area, where it is more easily compensated for by an increased deployment of gas-fired power plants. Yet this short-term cost optimisation does not pay out in the long term if more ambitious emissions targets are to be reached and the electrification of these heating systems becomes indispensable. In the long view, the flexibility of power devices such as heat pumps and electric vehicles is essential for integrating fluctuating renewable energy. Flexibility and the use of bivalent heat pump systems and trolley trucks can both help reduce peak demand.

As a rule, heat pumps increase peak demand. In the sensitivities considered here, the highest output range demanded from heat pumps is 10 to 21 GW. On a whole, the sensitivity calculations show the conditions that need to be met in order to reach 2030 climate targets. Given the uncertainties about further developments in building insulation and electric vehicle use, Germany must aim at a robust minimum level of heat pump installations for 2030 so as to compensate for any shortfalls in these areas. 5 million heat pumps represent a robust minimum level.

A climate friendly building heating mix in 2030 consists of 40 percent natural gas, 25 percent heat pumps, and 20 percent heat networks

After taking efficiency measures, a climate friendly coverage of the 547 TWh of remaining energy use for heating in household and commercial buildings is met by a mix of natural gas, heat pumps, small-scale distributed heating systems and district heating.

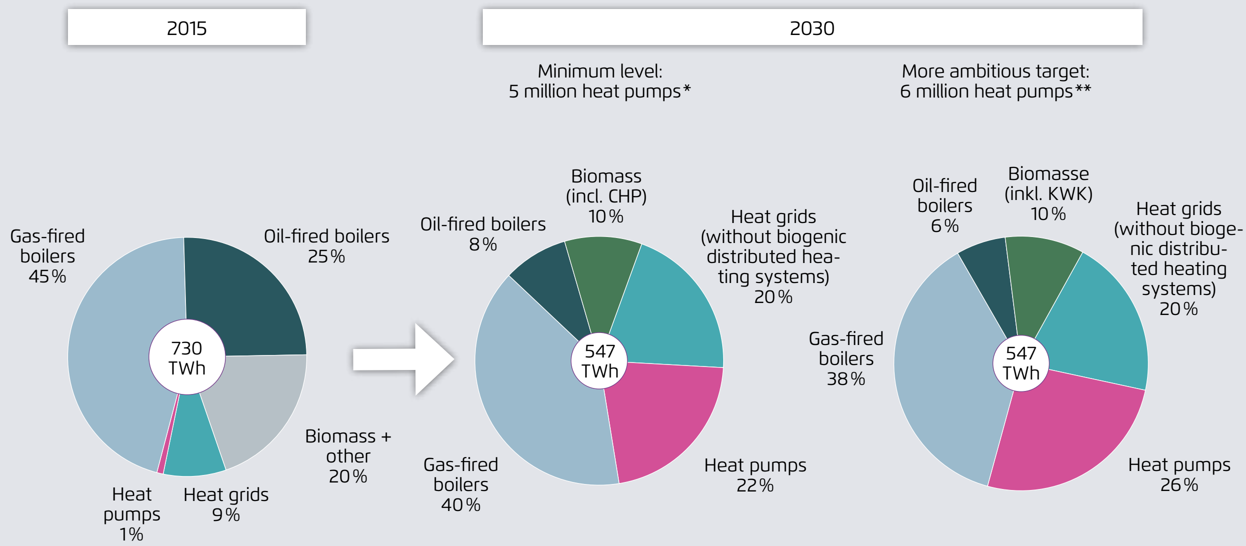
The calculation of the Emob(-) sensitivity with **5 million heat pumps** for 2030 yields the following shares in energy consumption for heating (Figure 7): 40 percent from gas-fired boilers, of which around half must be added by 2030; 22 percent from heat pumps, with more than half consisting of ground source heat pumps and just under one third consisting of bivalent air source heat pumps, operated in combination with gas-fired boilers[10]; 20 percent from district heating networks; 10 percent from biomass including biogenic distributed heating systems; and 8 percent oil-fired boilers. Relative to the distribution in 2015 – a total energy consumption of around 730 TWh for heating – the largest change by percentage is oil heating, which shows the highest specific CO_2 emissions. The oil share drops from 25 percent (2015) to 8 percent (2030). Gas-fired heating systems, which emit less CO_2 than oil, falls only five percentage points in the same period. Heat pumps and heat networks show the greatest gains.

The more ambitious target for heat pumps – **six million installations by 2030** – keeps the option open of reducing greenhouse gases emissions by 95 percent by 2050. This target creates further shifts in the heating mix for buildings. Below, these shifts are illustrated using an extrapolation assuming that total energy for heat consumption remains constant. If the additional energy from additional heat pumps is deducted equally from oil and natural gas, the result is

10 "Hybrid heat pumps" combine both types of heat generators in a single unit (BDH 2014).

Heating mix for buildings in 2015 and 2030 with two different targets for heat pumps as a share of energy consumption for heating (by percentage)

Figure 7



* Heating system shares according to EMob(-) sensitivity
** Extrapolation of EMob(-): The amount of energy of a million additional heat pumps (24 TWh) is deducted equally from gas- and oil-fired boilers provided that total energy consumption for heat remains constant.
BMWi 2016 (for 2015); own calculations (for 2030)

the distribution on the right in Figure 7, with 6 percent from oil-fired boilers, 38 percent from gas-fired boilers and 26 percent from heat pumps.

For 2030 we need a renewable energy target of at least 60 percent of gross electricity use

Germany aims to reduce greenhouse gases by 55 percent relative to 1990 levels by 2030. Furthermore, Europe's present resolutions on combatting climate change require that Germany reduce its greenhouse gas emissions outside the EU ETS by 38 percent compared with a baseline of 2005. The model used here takes into account both of these restrictions. There are other input parameters that can influence 2030 results. On the supply side are output requirements for coal-fired power stations,[11] fuel price assumptions and renewable energy costs. The primary factor on the demand side is net electricity export of 32 TWh,[12] followed by new electricity consumers in the heating and transportation sectors and the above-mentioned assumptions about building efficiency and electric car use.

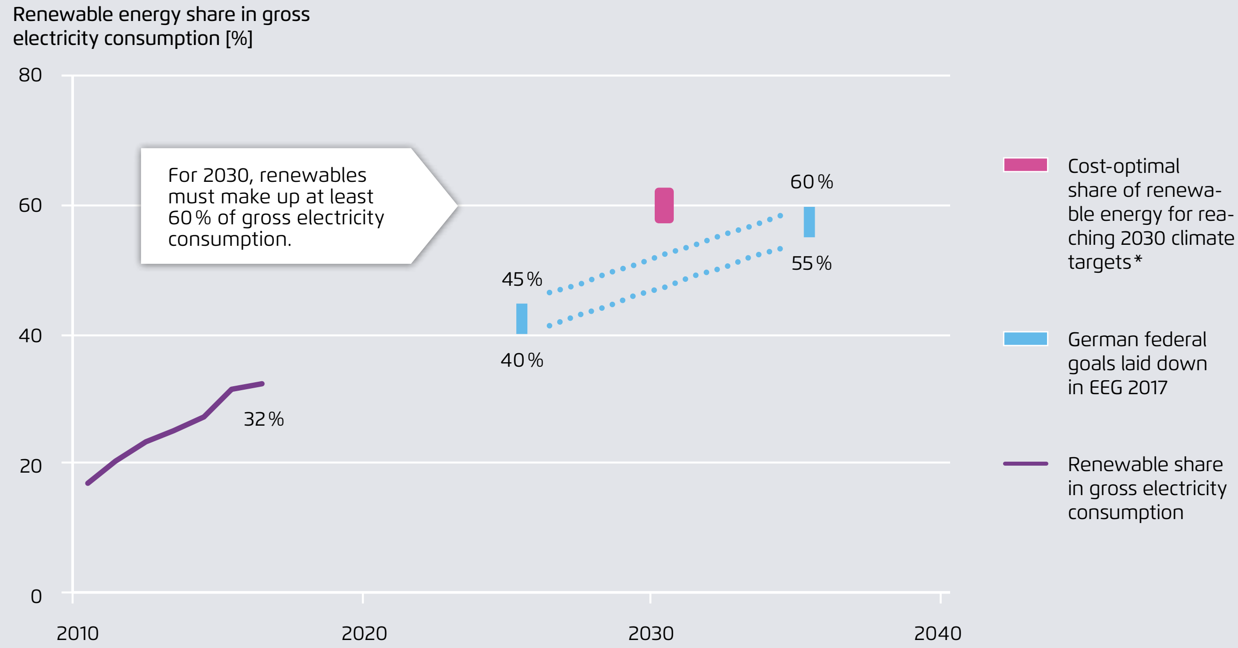
To adhere to the imposed emission limits, various decarbonisation options can be used in the model, such as the addition of gas-fired power plants and renewable energy. The most favourable mix will then be selected based on these options. Under the assumptions stated above, the 2030 sensitivity calculations yield a cost-optimal renewable energy share in gross electricity consumption between just under 58 percent and 62 percent (Figure 8).

11 This is based on the coal consensus path recommended by Agora Energiewende (Agora Energiewende 2016).

12 This the projected result of a European electricity market simulation for 2030.

Share of renewable energy in gross electricity consumption by percentage

Figure 8



* 55 percent reduction of total greenhouse gas emissions relative to 1990 levels and a 38 percent reduction of greenhouse gas emissions outside the EU ETS relative to 2005 levels.

Authors' own illustration

The results show that the current renewable energy targets – from 40 percent to 45 percent by 2025 and from 55 percent to 60 percent by 2035 – do not suffice to meet the 2050 climate protection goals while minimizing costs. For this reason, the 2030 targets of the Renewable Energy Sources Act (EEG) must be raised to at least 60 percent.

Heat pumps or "green" gas?

The comparison of energy system target scenarios as well as the sensitivity calculations come to the same conclusion: heat pumps should play an important role in heat supply in the future. Yet some voices in the energy policy discussion have questioned this conclusion. A frequently raised counterargument is that a rapid and expansive installation of modern gas-fired condensing boilers would reduce CO_2 emissions more quickly and more affordably. To address this controversy, the most important challenges for heat pumps will once again be named, and then compared with those of gas-fired heating systems.[13] The criteria for the comparison are greenhouse gas emissions, energy efficiency and effects on peak demand.

While **greenhouse gas emissions** from a gas-fired boiler remain the same over time, the already low emission intensity of heat pumps decreases as the renewable energy share in electricity generation increases. As future electricity demand rises from new heat applications,[14] renewable electricity generation needs to be expanded correspondingly. To keep up with renewable electricity, gas must become increasingly "green."[15] Since the potential of biomass

13 More technical details are presented in chapter 6.1 in appendix 7.2 of Fh-IWES/IBP (2017).

14 A more in-depth discussion of heat pump electricity's emission intensity can be found in chapter 3.4 (Fh-IWES/IBP 2017)

15 See BDEW et al. (2016).

is limited,[16] natural gas will have to rely on power-to-gas if it is to contribute to extensive decarbonisation. The issue is in which application to use renewable electricity: heat pumps or power-to-gas.

In view of the limited surface potential of renewable energy in Germany and foreseeable societal resistance, much attention will have to be paid to using each kWh of electricity from renewable sources as **energy-efficient** as possible. While heat pumps – by using ambient heat – produce around 3 to 4.5 kWh of thermal heat per kWh of electricity, power-to-gas only produces between 0.24 and 0.84 kWh of heat per kWh on account of conversion losses.[17] The heat yields of these technologies differ by a factor of 4 to 19. Of course, power-to-gas has the added benefit of long-term storage.[18] But even if the seasonal heat storage losses for heat pumps are taken into account, the results do not change substantially.[19] From the standpoint of efficiency, the use of electricity in heat pumps is clearly better than power-to-gas.

An important challenge when simultaneously operating a large number of heat pumps (or, in the future, electric vehicles) is the **increase of peak demand.** An electricity system with increasing shares of wind and PV can experience times of higher or lower levels of generation from renewables (though wind turbines are generally better suited to meeting the electricity demands of heat pumps during the heating period). These fluctuations include periods with little PV and little wind, so-called *Dunkelflauten.* In addition, when temperatures are very low, heating needs are high and heat pumps become very inefficient.

The modelling in this study captures these relationships as far as possible to determine influence on peak demand. For the 2006 meteorological year, the model simulates fluctuating renewable generation at hourly intervals, along with dynamic, outside temperature-dependent heat pump performance coefficients, which differ by technology and building type.

When it comes to increased peak demand, it is important to distinguish between questions of supply security – that is to say, the output reserve for critical times during the year – and power generation from thermal power stations over longer periods of time, such as during periods when there is little sun and wind. Three relevant cases must be considered here:

1. Through 2030, the increased demand for power output from heat pumps ought to be bearable, as the above sensitivity calculations show. It is true that heat pumps require up to 21 GW of additional peak demand. But given the approx. 35 GW of output needed today for direct electric resistive heating (especially for flow-type heaters and night storage heaters), exchanging night storage heaters for heat pumps or efficient gas-fired boilers can enable the introduction of more heat pumps into the electricity system.
2. In 2050, the coverage of demand load depends, among other things, on the greenhouse gas reduction targets and on the remaining emissions budget. With the emission target of -80 percent by 2050, the electricity sector may continue to emit (small quantities of) CO_2, so that peak demand can be covered relatively affordably by additional gas turbines.[20]
3. With the more ambitious climate protection target of -95 percent , the electricity sector may not emit any more CO_2 in 2050 because the remaining emission budget must be reserved for the non-energy emissions, which are difficult to decarbonise. To be able to cover peak demand, gas-fired power stations must rely on power-to-gas. But because of

16 See chapter 3.1 of Fh-IWES/IBP (2017) and Fh-IWES (2015).

17 FENES et al. (2015, Tab. A 2.5.1). The use of waste heat in decentralized power-to-gas facilities can help improve yield (dena 2016).

18 This property makes power-to-gas a very important technology for long-term storage in electricity systems with a high share of renewable energy (FENES et al. 2014).

19 See Prognos, ifeu, IWU (2015, Tab. 3–6).

20 See appendix 7.3 of Fh-IWES/IBP (2017), which illustrates the additional costs of gas turbines relative to heat pumps.

the high power-to-gas conversion losses, this form of output security is more expensive than in the case of natural gas. Nevertheless, these additional costs are negligible when compared with other possible decarbonisation options due to the few hours per year that this occurs.[21]

In other words, the demand peak problem for heat pumps is controllable. By contrast, this problem does not occur with gas, since the gas infrastructure is sufficiently dimensioned for such heating loads.

What is probably the greatest challenge for heat pumps is the need for sufficient **building efficiency.** That is to say, whether they catch on much depends on whether the heat demands of buildings can be lowered, especially in existing building stock. Building heat demand was simulated in the study's calculations based on several assumptions. For instance, the sensitivity calculations assumed a rise in the retrofit rate to 2 percent together with a high retrofit depth. If consumption cannot be reduced correspondingly in real life, the technical requirements will not suffice for the massive expansion of heat pumps. On the other hand, a complete green retrofit need not be required in old building stock for the installation of heat pumps. The modernisation of windows and roofs can achieve much in this regard. Floor heatings are also dispensable if low-temperature radiators are installed, whose performance is only negligibly worse. Moreover, bivalent air source heat pumps may serve as a bridge technology in combination with gas- or oil-fired boilers for times when it is very cold as a way to handle the challenge of gradual green retrofitting. To avoid lock-in effects, the installation design should ensure that heat pump output suffices to supply the building after extensive modernisation. Moreover, more innovative heat pump technologies exist – combinations of ice storage tanks with solar absorbers, highly efficient director evaporators, etc.[22] There are, in other words, different ways of making building stock compatible with heat pumps.

What this study did not consider was **possible distribution network implications** when many heat pumps are used simultaneously. This can lead to additional costs that are not recorded in the model used here. Yet the expansion of distribution networks is pending in any case and is unlikely to be challenged even with reference to the already existing gas distribution networks.[23]

All in all, the rapidly rising use of heat pumps in the building heating sector appears to be an energy-efficient way to reduce greenhouse gases in the power sector that can be controlled during peak demand. Its Achilles' heel is that old building stock requires a minimum level of energy modernisation, which natural gas-fired boilers do not require. However, gas as a source of energy must also contribute to **decarbonisation** and become increasingly more "green" over time. This will raise the cost of gas, making sufficient insulation worthwhile even in buildings heated with gas. In the long term, the use of green gas in the building stock without a green retrofit makes little sense from a cost perspective. Decarbonisation with gas may be somewhat easier to begin with when it comes to the green retrofitting of the building exterior. But this alone does not ensure a low-cost path for reaching 2050 climate targets. If green gas will have a role in the decarbonised building sector, then it might be because of consumer preferences. If some people prefer to continue to heat their homes with gas instead of subjecting them to a green retrofit or installing a heat

21 The power-to-gas reconversion in a combined cycle gas turbine power plant generates only 0.3 to 0.38 kWh electricity per kWh (FENES et al. 2015, Tab. A 2.5.1). But this electricity then generates more thermal heat via heat pumps by using ambient heat. It is only the few hours in which the temperature falls below zero Celsius, the performance coefficient (COP) of air source heat pumps drops below 2.5 and – simultaneously – renewables do not feed-in electricity that the efficiency of power-to-gas reconversion with heat pumps is worse than a combination of power-to-gas with a condensing boiler.

22 See chapter 6.1 and appendix 7.2 of Fh-IWES/IBP (2017) for details.

23 See E-Bridget et al. (2014).

pump, then they should be able to do so. But, like electricity, gas must become increasingly more green, and in the process it will become more expensive.

Natural gas can be made green in two ways: (1 through tighter CO_2 benchmarks and primary energy factors for heating systems and/or (2) through a requirement that more and more CO_2-neutral gas be added by means of the limited quantities of available biomass and with power-to-gas technology.

The question for future studies is this: which path is better for the majority of existing buildings in the long term, the way of heat pumps or the way of green gas? Given the appreciable competition in Germany for renewable energy space, the answer will significantly depend on the costs of producing future power-to-gas products such as hydrogen and synthetic natural gas abroad and importing them to Germany. Another decisive factor is the power-to-gas consumers in the transportation and industrial sectors with which the building heating sector will have to compete, as in some cases these competitors will be harder to electrify than building heat, if they can be electrified at all. Future studies need to investigate these questions more closely.

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