Climate-neutral power system 2035

How the German power sector can become climate-neutral by 2035

EXECUTIVE SUMMARY

Agora Energiewende

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Prognos AG carried out the electricity market modelling (Chapter 2 in full German study) and Consentec GmbH the electricity grid modelling (Chapter 3 in full German study).

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Preface

Dear reader,

The need for action has never been greater in German energy policy. Against the backdrop of an accelerating climate crisis, and on the heels of spiking fossil-fuel prices, Germany is now facing an acute geopolitical threat to its fossil gas supplies.

The public debate is currently dominated by crisis response measures, including in particular the need to diversify fossil gas imports and ease the pressure of high energy prices. However, paramount attention should also be devoted to structural solutions – most importantly, the systematic expansion of renewables, in combination with greatly enhanced energy efficiency.

This study aims to look beyond short-term fixes and advance sustainable solutions to the current predicament. It shows how the share of renewables in German electricity consumption can be increased to 80 percent by 2030 – the first study to do so using comprehensive electricity market and grid modelling.

Achieving this target will require a massive build-out of renewables and energy infrastructure. If this build-out succeeds, it will trigger a growth dynamic that enables the achievement of a climate-neutral power system by 2035.

In addition to the familiar need to act on the expansion of renewables and power grids, our findings emphasize that measures for greater electrification and demand flexibility must be developed and implemented without delay.

Renewable electricity is the key to achieving climate neutrality, and the foundation for Germany's future as an industrial powerhouse. The solutions are on the table, yet time is of the essence. Now is the moment for ambitious action.

I wish you an enjoyable read!

Simon Müller
Director Germany, Agora Energiewende

Key findings at a glance:

1. **By 2030, renewable energy can cover 80 percent of electricity consumption in Germany if the expansion of wind and solar PV is given much higher priority in combination with a paradigm shift in the development of power and hydrogen grids.** Faster planning and approval procedures and the accelerated adoption of an integrated system development plan are crucial.

2. **80 percent renewable electricity by 2030 and gas-fired power plants that increasingly run on renewable hydrogen can ensure the timely phase-out of coal and enable a climate-neutral power system by 2035.** For this transition to succeed, reliable investment conditions must be ensured.

3. **The switch to green electricity in industry, buildings, and transport by means of electrolysers, electric vehicles, heat pumps and electrode boilers must be implemented from the start in a manner beneficial to the overall system.** This requires a swift reform of grid charges, the intelligent operation of distribution grids and a consistent smart meter rollout.

4. **Secure power grid operation with 100 percent renewable energy requires a broad technology portfolio for the provision of system services and the efficient management of grid bottlenecks.** To this end, a package of measures for reliable power grid operation given a 100 percent renewable energy share must be implemented and the introduction of location-based power-price signals must be examined.

Content

1 Summary and measures

1.1 Motivation

Germany's new coalition government has set ambitious goals, adopting a coalition agreement that stipulates an 80 percent renewables share in power demand by 2030 – in parallel to a continued growth in consumption. Furthermore, within the framework of its G7 presidency, Germany has successfully advocated for the G7 countries to aim for a predominantly decarbonised power sector by 2035.

The transition to a renewable electricity system represents a crucial stepping stone and enabler of the broader transition to a climate-neutral economy. In the future climate-neutral world, renewable electricity will be at the beginning of almost every energy supply chain; increasing electrification will thus enable greenhouse gas reductions in other sectors. Fossil energy sources, however, can only be replaced if sufficient renewable electricity is produced and can reach suitably equipped consumers – either directly, given the electrification of processes, or indirectly, in the form of hydrogen or synthetic energy carriers. The more energy efficient existing and new consumers are, the more easily this can be achieved.

1.2 Research question and methodological approach

The scenario "Climate-neutral Electricity System 2035" (KNS2035) presented here is dedicated to the question of how the transition of the German electricity system to renewable energy can be achieved by 2035. It analyses the consequences of such a transition for electricity generation and consumption as well as for grid expansion and operation. It builds on the study "Climate-neutral Germany 2045" (KNDE2045), which modelled an economy-wide climate neutrality transformation scenario. Based on KNDE2045, KNS2035 updates the existing model based on the new government targets for renewable electricity generation and consumption. Prognos AG, which provided the electricity market modelling for KNDE2045, calculated an updated electricity market model for this purpose. Based on this, Consentec GmbH prepared a supplementary grid analysis.

1.3 Core results

The KNS2035 scenario shows a feasible path for achieving an 80 percent renewable energy share in gross electricity consumption by 2030. It also demonstrates that the continuation of the path to 80 percent renewable electricity in 2030 will lead to a climate-neutral power system in 2035. Simultaneously, the phase-out of coal by 2030 is achieved through market instruments and the consistent and accelerated expansion of renewable energy; coverage of residual load is ensured by dispatchable gas-fired power plants. The rapid conversion to renewable hydrogen or hydrogen derivatives reduces fossil gas consumption and greenhouse gas emissions.

At the same time, this analysis underscores the magnitude of the challenge: the addition of wind and solar power plants increases from 7 gigawatts (GW) in 2021 to as much as 29 GW in 2025 and peaks at 39 GW in 2030. The electricity transmission grid will be strengthened and expanded in parallel, so that by 2035 it will cover around 50,000 circuit kilometres – an increase of around 15,000 circuit kilometres compared to today. Electricity demand will increase by 146 terawatt hours (TWh) by 2030, reaching 726 TWh. By 2035, another 168 TWh will be added. This growth in demand is driven by rapid electrification in industry, buildings and transport. In addition, the transformation to a climate-neutral electricity system also requires that low-voltage distribution grids in particular are controlled far more intelligently and that new consumers such as electric vehicles, electrolysers and heat generators are systematically operated in a flexible way.

Thus, achieving the goals requires a paradigm shift in core areas of the electrical system. In particular, planning and approval procedures for renewable energy systems and electricity and hydrogen grids must be consistently simplified and accelerated. Furthermore, an integrated system development plan for electricity, fossil gas and hydrogen grids is urgently needed for the coordination of infrastructure development. The necessary measures must be enacted immediately.

1.3.1 Generation

By 2035, renewable electricity generation will increase to 845 TWh in the KNS2035 scenario due to the continued strong expansion of wind energy and photovoltaics (Figure 1). Indeed, wind power and solar energy will undergo massive expansion to become the main pillars of the climate-neutral electricity system of 2035. For this to succeed, the annual expansion of rooftop and ground-mounted solar PV must be more than quadrupled in rapid fashion, from 5 GW in 2021 to an average of 21 GW between 2026 and 2035. In the same period, the expansion of onshore wind power must be increased from 1.7 GW to 10 GW per year – that is, by a factor of approximately six. The annual addition of offshore wind power peaks at 8 GW and amounts to 6 GW from 2031 to 2035. Onshore wind turbines will make the

Net electricity generation in the KNS2035 scenario Figure 1

Prognos (2022)

Fossil gas*: Electricity generation from fossil gas, which could lead to further emissions reductions if replaced with synthetic fuels largest contribution to net renewable electricity generation, accounting for a 40 percent share. Solar PV contributes one third, while offshore wind energy accounts for one quarter.

In 2035, 89 percent of renewable electricity is directly generated by renewables and 7 percent is generated in hydrogen power plants. Since the amount of renewable electricity generated exceeds domestic electricity consumption, Germany is a net electricity exporter and the share of renewable electricity is, statistically, over 100 percent.

To back-up this dependence on variable renewables, dispatchable gas-fired power plants are used in the 2030s to cover the residual load. Generation from these plants trends downward, from 107 TWh in 2030 to 86 TWh in 2035. In the climate-neutral electricity system of 2035, the installed capacity of gas-fired power plants doubles from 30 GW (2022) to 61 GW.[1] Fossil gas is increasingly replaced by hydrogen, so that the share of fossil gas in electricity generation is only two percent in 2035.[2]

In 2030, electricity generation from hydrogen amounts to about 13 TWh. This will require 4 to 6 GW of hydrogen-capable power plants. In 2035, gas-fired power plants will generate 86 TWh of electricity. Gas-fired power plants are mainly needed to ensure security of supply in the winter months. One third of the gas-fired power plants (20 GW) generate 75 percent of the total gas-fired electricity production in 2035. Another third only operate a few hours per year. The achieved degree of hydrogen conversion and the availability of hydrogen determine the residual emissions of electricity generation.

For the successful implementation of the energy transition, three ramp-up paths in the hydrogen sector are crucial and must be initiated immediately: hydrogen production; hydrogen-capable power plants; and hydrogen infrastructure. Starting now, new power plants must be 100 percent H_2-ready. To ensure that the production and consumption of the rapidly increasing amounts of hydrogen can be coordinated in terms of location and time, new hydrogen transport and storage infrastructure will be necessary. The options of using the hydrogen derivative ammonia in power plants must also be examined in order to counter shortages in hydrogen supply, as ammonia is particularly easy to import.

1.3.2 Electrification, flexibility and electricity consumption

The level of future electricity demand is a key driver of the necessary expansion of renewable energy and the electricity system as a whole. Energy efficiency measures make an important contribution to limiting the scope of expansion needed. Conventional electricity consumption stagnates as efficiency increases and an increasing number of consumers offset each other (Figure 2). At the same time, the increasing electrification of industry, transport and buildings as well as hydrogen production raise electricity demand to around 725 TWh by 2030. Electrification of these sectors significantly reduces German greenhouse gas emissions.

With increasing feed-in from fluctuating renewable energy and a decline in conventional power plant capacity, new flexibility options are required to ensure a balance between supply and demand (Figure 3). On the demand side, electromobility, heat generators and electrolysers can and must be operated in a manner beneficial to the overall system in order to strengthen the integration of wind and solar power. Battery storage and pumped storage power plants also offer considerable flexibility potential.

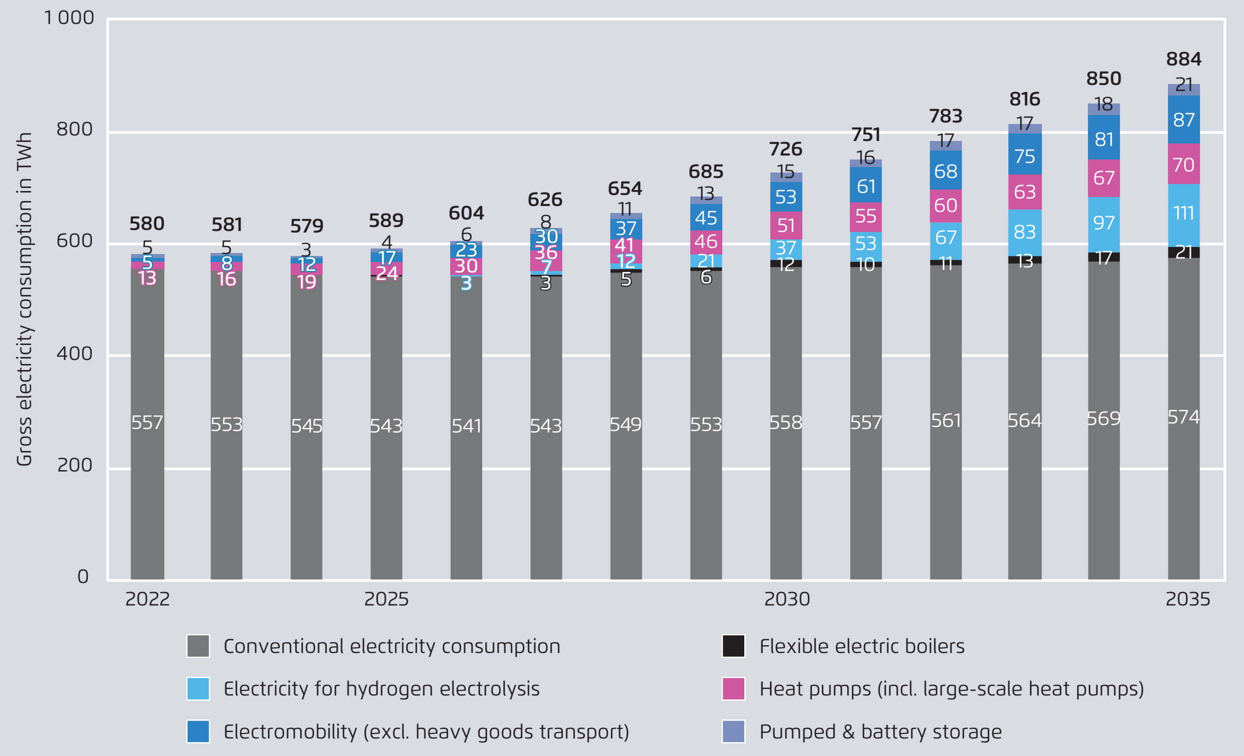
Electric vehicles, for example, can be flexibly charged to a certain extent. Furthermore, electric vehicles can act as electricity storage through bidirectional charging (also called vehicle-to-grid). Assuming that 25 per cent of electric cars will use vehicle-to-grid in

1 Of this, 64 TWh is hydrogen and 18 TWh is fossil gas.

2 In addition, there is one percent from the combustion of waste and blast furnace gas.

Gross electricity consumption in the KNS2035 scenario

Figure 2



Prognos (2022)

2035 and that 40 per cent of these vehicles will be made available to the electricity market on average, the usable power amounts to 28 GW. Although the power can only be provided for short periods of a few hours, vehicle-to-grid reduces the need for small battery storage in homes as well as the need for large battery storage. It thus contributes to the efficient use of renewable electricity and resources.

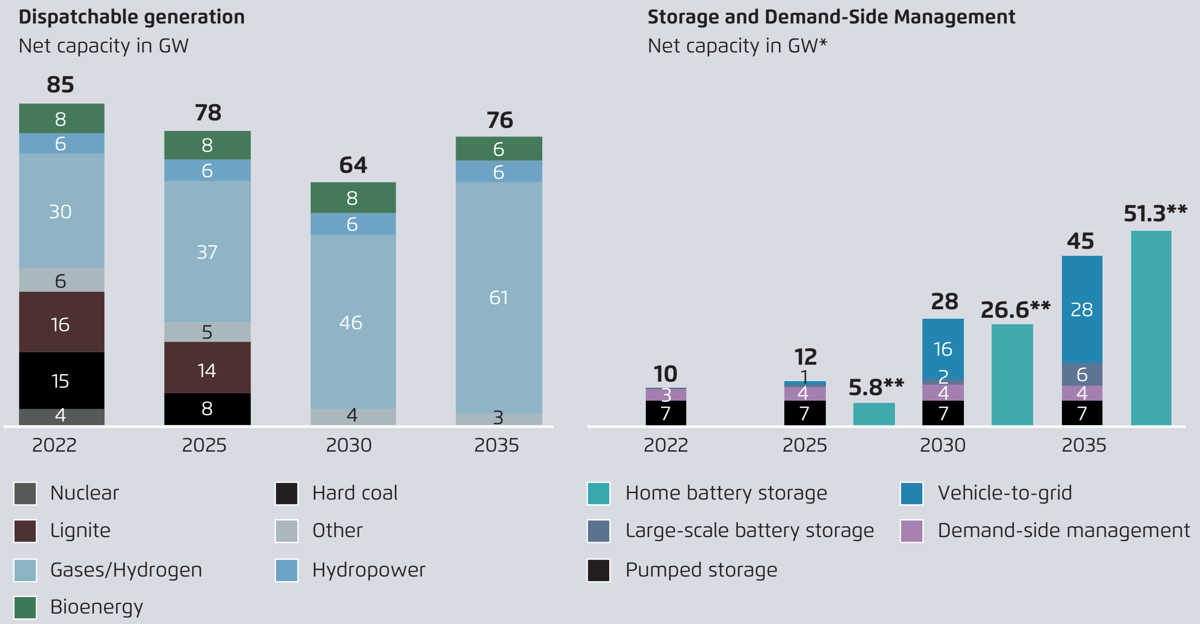
Heat pumps offer additional demand-side flexibility, provided that the majority of the almost nine million heat pumps in 2035 can be controlled via software interfaces. Flexibility is made possible by the storage potential of the buildings themselves and buffer storage in the heating circuit. This can be used depending on the outside temperature-dependent heat demand and user-side approval of temperature bandwidths.

Direct power-to-heat (PtH) applications such as heating rods and electric boilers are a favourable flexibility option for integrating electricity into heat applications (industry, local heating, district heating, etc.) during hours of high renewable energy feed-in, rather than curtailing generation.

The installed capacity of power-to-heat appliances is 10 GW in 2030 and 20 GW in 2035.

Electrolysers offer further demand flexibility. In the KNS2035 scenario, about 12 GW_{el} are in use in 2035. The electrolysers produce hydrogen during periods of high renewable generation when electricity cannot be used or transported elsewhere. Electrolysers are built especially in northern Germany at locations before grid bottlenecks.

Flexibility options including dispatchable generation in the KNS2035 scenario — Figure 3



Prognos (2022)

* Average storage capacity: battery storage = 1 hour, pumped storage = 8 hours | Demand-side management (DSM) = short-term load shifting potential in industry | Vehicle-to-grid: battery-electric vehicles that can also feed into the power grid from their battery.

** Home battery storage systems are partially operated for self-consumption

Thanks to their fast response time, battery storage systems offer a wide range of potential stationary and mobile applications. Due to their electrochemical properties, they have an efficiency of up to 99 percent and can be used by households, industrial firms, energy suppliers, PV and wind farm operators and system service providers. The installed capacity of decentralised battery storage (in combination with PV rooftop systems) is 27 GW in 2030 and 51 GW in 2035.

The more it becomes possible through suitable price signals to rely on existing technical flexibility, the more renewable electricity can be used directly. At the same time, this reduces the need to add gas-fired power plants and provide for their necessary fuel inputs.

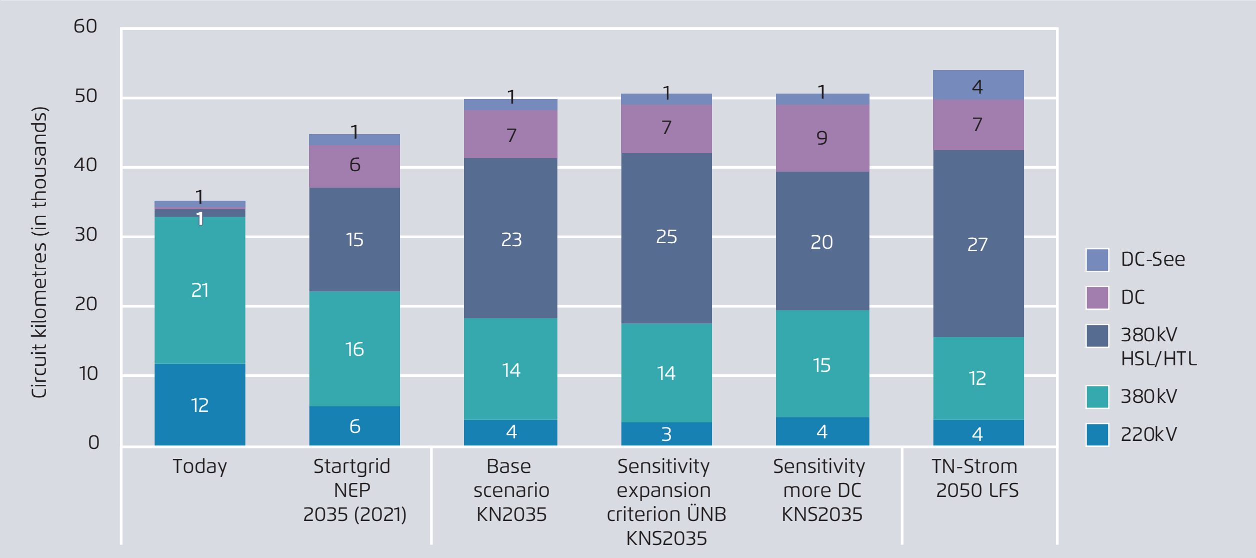
1.3.3 Energy infrastructure

The climate-neutral power system of 2035 is just an intermediate step in terms of German grid expansion: First, electricity demand will continue to grow after 2035 due to increasing demand from other sectors. Second, with increasing shares of renewable energy and the expansion of interconnection capacities, the exchange of electricity within Europe will also become significantly more important beyond 2035.

In order for the integration of renewables to succeed, the electricity grid must be expanded as quickly as possible and the transformation towards flexible, optimised and secure grid operation must be accelerated. In the KNS2035 scenario, the total circuit length in the German transmission grid grows from approximately 35,000 circuit kilometres in 2021 to approximately 50,000 circuit kilometres in 2035 (Figure 4). Due to long implementation periods, all projects

Structural composition of German power grid

Figure 4



Consentec (2022)

DC - direct current, HSL - high voltage line, HTL - high temperature line, kV - kilovolt, LFS - long-term scenario, NEP - grid development plan, TN - greenhouse gas neutral, ÜNB - transmission grid operator

required for this growth must be implemented in the coming years. Accordingly, grid expansion and reinforcement measures should be prioritized and accelerated.

It can be assumed that even with significantly accelerated grid expansion, structural grid bottlenecks will remain in the German transmission grid. To safeguard power transmission, a diverse portfolio of grid optimisation, reinforcement and expansion technologies will likely be needed. Comparatively novel but readily available technologies that can play a role in this context include, for example, sensor-based measurement of real-time line capacity and FACTS-based load flow control. Further options are the meshed operation of HVDC systems as well as so-called virtual lines, which enable the time-delayed transmission of electrical energy through the coordinated counter-rotating operation of battery storage systems.

At the same time, the challenges attendant to grid operation in a system dominated by renewable energy must be tackled quickly. Necessary measures include implementing a system for real-time assessment of transmission grid stability; guaranteeing sufficient instantaneous reserves; and ensuring necessary reactive power and short-circuit current contributions while guaranteeing the ability to restore the grid.

Electricity and hydrogen grid planning undergoes significant change as the electricity, transport, heat and industrial sectors become increasingly integrated through electric vehicles, electric heat generators and electrolysers. The rapid availability of a sufficiently dimensioned hydrogen grid and storage infrastructure in order to temporally decouple hydrogen production and demand is an indispensable prerequisite for the optimal siting of electrolysers and dispatchable gas-based generation plants from a power system perspective. However, the currently separate planning processes for electricity, gas and hydrogen grids do not reflect this need at present.

Additional fossil gas savings in scenario KNS2035

In the KNS2035 scenario, the faster expansion of renewable energies leads to a significant reduction in Germany's dependence on fossil fuel imports. Based on the previous study "Climate-neutral Germany 2045" and the simplified consideration of changes through which fossil gas can be replaced through increased use of electricity, Prognos AG estimated the decrease in fossil gas demand up to 2030 in the KNS2035 scenario (Figure 5).

Based on a fossil gas demand of 861 TWh in 2018, the demand could be reduced to about 620 TWh by 2030. The main levers for saving fossil gas in the medium term are building renovation, the use of heat pumps, expansion of district heating networks, efficiency improvements in industry, and the increasing electrification of processes, especially the provision of process heat by large heat pumps and electric boilers.

Levers for reducing fossil gas consumption in the KNS2035 scenario — Figure 5

Prognos (2022)

LHP - large-scale heat pumps

* Including expansion of solar thermal, biomass, decline in cross-sectional applications, cooking gas, etc.

** 2030 value from Climate-neutral Germany 2045 scenario, for comparison: 725 TWh

At the same time, the greater flexibilization of electricity consumption increases the demands on market design. Prices must provide incentives for behaviour that benefits the grid, especially when it comes to flexible consumers. If, for example, grid bottlenecks are not taken into account in pricing, a very low electricity price can lead to the activation of flexible consumers without the electricity demand triggered by this actually being covered: if the consumers are behind a bottleneck, the cheap electricity cannot be brought to the consumers. As a result, redispatch measures would have to be taken. These would either trigger additional costs or the available capacities might not be sufficient if there is a very strong spike in demand. Augmenting the spatial differentiation of electricity prices can avoid these challenges.

1.4 Conclusions and recommendations for action

1.4.1 Planning and approval procedures

The planning and expansion of electricity grids and hydrogen infrastructure have particularly long lead times. Therefore, integrated system planning is urgently needed.

The main difference between the electricity sector in the present KNS2035 scenario and the KNDE2045 scenario is a shortening of the transformation period. Since there are only eight years left until 2030 and 13 years until 2035, the necessary lead time for transformation measures is of outstanding importance. As a result, a particular focus must be placed on the expansion of the electricity grid and the development of the necessary hydrogen infrastructure (generation/imports, base grid, storage). In this connection, an integrated approach is essential for coherent planning that enables target fulfilment. At present, however, electricity and gas grids are planned separately. Therefore, a change in planning procedures is necessary:

→ An integrated system development plan for electricity, fossil gas and hydrogen needs to be developed by mid-2024. This will set forth the overall grid infrastructure required for climate neutrality. The planning process must consider all levels of the grid, from low-voltage distribution up to national interconnections at the European level.

The speed of renewables expansion and development of electricity and hydrogen grids will set the pace for the transition to a climate-neutral power system. The rigorous acceleration of planning and approval procedures is needed to achieve the necessary speed.

The KNS2035 scenario envisages a very rapid ramp-up of renewable energy capacity and the annual build-out will remain very high for about a decade. To ensure that the necessary infrastructure is in place in time, projects must be planned and implemented quickly. The regulatory conditions in Germany are currently not designed for such a transformation. The new federal government has already implemented a number of measures. For example, in its draft legislation to amend the Energy Industry Act (EnWG), the federal government has proposed, among other things, amended requirements for the preparation of the scenario framework by the transmission system operators (TSOs), which serves as the basis for the preparation of the network development plan. In future, the new horizon for consideration is to be the year 2045 and the new scenarios are to be aligned with the climate and energy policy goals of the German government. Furthermore, the distribution system operators (DSOs) will have to draw up target-based regional scenarios for planning regions covering a wide range of locations, and to submit grid expansion plans on this basis. At the same time, it is clear that relevant hurdles still exist or that new challenges could arise. In this respect, the following priorities apply:

→ It should also be possible to expand the grid on grounds of precautionary measures. To this end, the legal foundation for grid expansion needs could

be clarified so that it addresses temporary overcapacity and the option value of infrastructure.
- The system development plan to be created should provide a target scenario framework against which the transmission system operators must align their grid expansion.
- The data basis on which the expansion of the distribution grid is carried out should be made binding – for example, by basing it on binding forecasts of the renewable energy potential to be exploited locally (municipality, grid area).
- The allocation of 2 percent of federal territory for onshore wind should be carried out as quickly as possible and minimum distances to urban development that are mandated at the state level should be abolished.
- Species protection should be strengthened through improved population protection. Areas that are particularly suitable for wind energy and have low conflict levels in terms of nature conservation (go-to areas) should only be examined once for compliance with European species and nature conservation rules; time-consuming individual examinations should be eliminated.
- In order to be able to act proactively and at short notice, a scheme for the continuous monitoring of procedures should be established, particularly related to the time required reasons for delays.

1.4.2 Generation

A massive increase in the annual expansion of renewable energy is essential for achieving a climate-neutral power system. This will require favourable investment conditions.

The KNS2035 scenario foresees extremely high renewables expansion rates over many years. Yet this can only succeed if investments in new capacities are possible in good time, on a sufficient scale and at low financing costs. Financing aspects in particular are gaining in importance in the current environment of rising interest rates.

Given the need for a comprehensive transformation of the power system, it is likely that new renewables capacity will not always generate sufficient revenues on the electricity market to cover investment outlays. Specifically, phases of low market revenues for new wind and solar power plants are likely to occur in the coming years whenever flexibility and storage options are not (yet) available to a sufficient extent. For this reason, long-term measures to safeguard against potential revenue shortfalls experienced by wind and solar power plants will remain essential. However, the actual purpose of such safeguarding has changed: In the past, guaranteed feed-in tariffs were used to address the higher cost of wind and solar power. In future, by contrast, safeguarding measures will be needed to minimise the possible revenue risks faced by the cheapest generation technologies. This will require:

- A symmetrical market premium (Contracts for Difference, CfDs) as a further development of the current market premium model for wind and solar project tenders;
- Support for renewables expansion on the basis of long-term power purchase agreements (PPAs) through state safeguarding instruments (for example, purchase guarantees);
- Further simplification of the rules for self-consumption, prosumers and on-site supply in the context of local solutions for the simultaneous supply of renewable electricity and renewable heat.

Dispatchable power plants cover the demand when generation from renewable energy is low. New plants must be able to run 100 percent on hydrogen; their expansion must be ensured.

Dispatchable power plants are indispensable in a power system based on renewable energy. Used to cover the residual load, they guarantee that electricity supply and demand are in harmony and thus make a significant contribution to maintaining security of supply, especially during longer phases of low wind and solar feed-in.

In the KNS2035 scenario, dispatchable power plants fall into very different categories: Part of the power plant fleet (around 20 GW) runs for an average of three thousand hours per year and provides the power system with additional energy quantities, which are then shifted according to demand using storage systems. High efficiency and the early use of hydrogen in these power plants are crucial for rapid climate neutrality.

A second group of power plants only runs for a few hours per year and guarantees load coverage during extreme weather years. These plants are an "insurance policy" against rare extreme events. In these power plants, efficiency is less important. Rather, the focus is on low investment and fixed costs and the simplest possible fuel logistics. Especially here, ammonia is a CO_2-free alternative to hydrogen as it is easier to store and transport. For this reason, a detailed examination of the possible uses of ammonia in the electricity sector is necessary.

Currently, there are a number of individual instruments that trigger new investment in dispatchable power plants. In addition to the purely market-driven addition of new capacity - which is not currently taking place – the incentives offered through the Combined Heat and Power Act (*Kraft-Wärme-Kopplungsgesetz*) as well as the capacity and grid reserves of the transmission grid operators are relevant in this context. None of the instruments in their current form are suitable for enabling hydrogen use in the German power plant fleet: The mere technical ability to use 100 percent hydrogen is by no means sufficient. Additional actions are required in this regard:

- → Clarify the investment framework for dispatchable power plants and consolidate the existing instruments into a simplified, clear system;
- → Introduce a market ramp-up instrument for the use of hydrogen and hydrogen derivatives in the power sector, especially in the area of combined heat and power.

1.4.3 Infrastructure

Even with a significant acceleration of grid expansion, structural grid bottlenecks remain in the transmission grid. The introduction of locational signals in the electricity market is thus unavoidable.

The current market design in Germany does not allow for spatial differentiation of the electricity price based on real-time supply and demand. Already today, this leads to a considerable need for redispatch: As a rule, power plants in northern Germany must be shut down and those in southern Germany have to be ramped up, as electricity volumes cannot be transported from north to south to a sufficient extent. This is often the result of a very high feed-in of renewable energy in the north. In addition, transit electricity flows through Germany occur on a market basis when, for example, prices are lower in neighbouring countries to the north and higher in neighbouring countries to the south than in Germany itself.

The inefficiencies associated with this arrangement increase significantly in a climate-neutral power system: First, the operating costs of hydrogen-based power plants are foreseeably high and hydrogen quantities are scarce. The use of such power plants for redispatch will therefore be more expensive than is currently the case. Second, low prices in the bidding zone trigger increasingly intensive demand growth through flexible loads: Thus, beyond a grid bottleneck, a flexible consumer would "see" a very low electricity price in the market and then increase consumption on this basis. Physically, however, this consumption would have to be covered by redispatch measures due to grid supply constraints. However, covering these flexible loads from hydrogen power plants thwarts the actual purpose of demand flexibility. Ultimately, these considerations show that the market price system in its current form is not suitable for a climate-neutral power system.

There are a number of ways in which geographic signals can be better taken into account in the electricity market. One long overdue step is to reform grid charges. In their current form, they are a significant barrier to flexibility (see section below on flexibility and demand). More far-reaching reforms, such as the division of the market into several bidding zones or the introduction of nodal pricing, were not investigated in this study. From the present analysis, however, it becomes clear that the introduction of geographic signals is unavoidable as part of the transition to a climate-neutral power system:

→ The options for introducing geographic signals need to be explored in more detail without delay.

Grid operation during times of 100 percent generation from renewables requires innovative operating concepts and technologies. These must be implemented quickly and reliably.

In a climate-neutral power system, grid operation occurs to large extent when generation from wind and solar is sufficient to cover demand. Conversely, this means that no dispatchable power plants (more precisely: power plants with synchronous generators) are needed to cover residual load. In order for a 100 percent renewable energy share to be practically possible in such situations, it will be necessary to implement a series of technical innovations in grid operation in good time. In addition to changes in the definition and procurement of system services, there is a need for a diverse portfolio of grid optimisation, reinforcement and expansion technologies.

These technologies and operating strategies are already largely known today. However, they must be implemented reliably and, above all, in good time in order to avoid unnecessary curtailment of renewable energy and ensure that targets are met. In many cases, market-based procurement or management in this area does not make sense, as the costs are very low in relation to the total system costs and a market-based organisation would be associated with high transaction costs. Instead, it is important to guarantee secure system operation through forward-looking regulation of the transmission system operators or the adoption of technical specifications at European level. This requires:

→ Development and implementation of a package of measures for 100 percent renewable energy system operation.
→ Introduction of a monitoring process for 100 percent renewable energy system operation.

1.4.4 Flexibility and demand

The current grid fee structure is a serious obstacle to flexibility. An immediate reform of the grid charges is indispensable in order to raise the necessary flexibility potential.

The current structure of distribution grid tariffs contradicts the requirements of a climate-neutral power system. The tariff structure does not vary in line with the current status of the power system. Thus, for larger customers (with load profile measurement), more constant electricity consumption is rewarded with low grid fees, and grid use for a few hundred hours is made unattractive with very high fees. The operation of a power-to-heat plant in a manner beneficial to the overall system, however, would require the opposite: particularly favourable grid usage for a few hours when the use relieves the grid. Overall, the transition to time-differentiated grid charges is a decisive lever for unleashing demand flexibilities. Reform can no longer be delayed:

→ Grid fees must be reformed in such a way that they support flexible grid use: Consumption should be possible at particularly favourable prices when large amounts of renewable electricity are available locally or when no (local) grid bottlenecks affect electricity purchases.
→ Existing exceptions that stand in the way of flexible grid use (7,000-hour rule) should be abolished.

- At the EU level, the German government should push for the design of grid charges to facilitate the energy transition in relevant EU legislation.

The intelligent control of decentralised flexibilities is an important pillar of a renewables-based power system. Intelligent distribution grid operation and a significantly faster smart meter rollout are necessary in this regard.

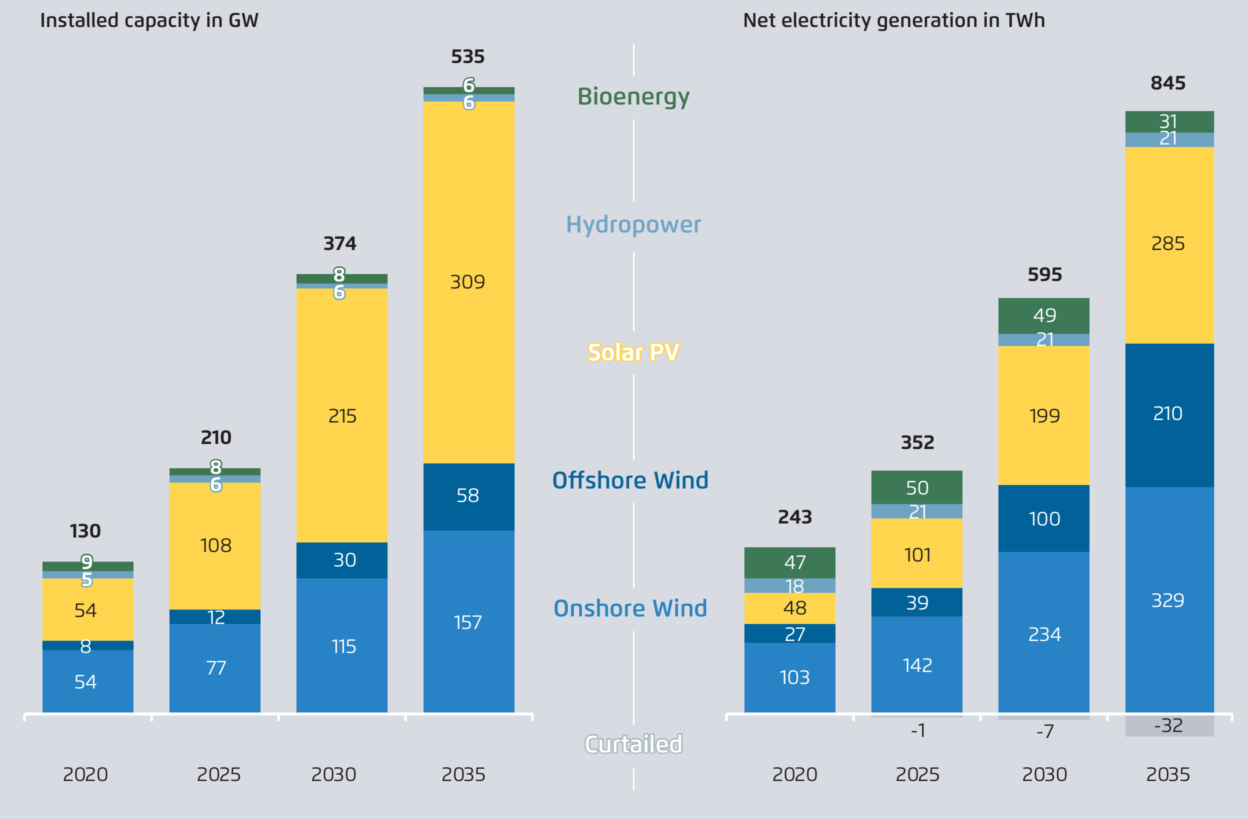
Decentralised flexibilities play a systemically relevant role in the KNS2035 scenario, which foresees a rapidly growing number of electric vehicles, heat pumps and home storage systems. Currently, the flexible operation of these systems is severely inhibited. The slow installation of smart meters means that variable electricity tariffs are hardly used in practice, preventing storage facilities and flexible consumers from being flexibly managed.

In this context, the active control of these consumption devices as well as the increased penetration of the distribution grids with power-generating appliances (for example, rooftop solar PV) make intelligent grid operation indispensable for reliably detecting and safely managing bottlenecks. Intelligent control of the grids also reduces the need for investment in grid reinforcement. Therefore, the following measures should be taken:

- Grid regulations should be adapted to create effective financial incentives for distribution system operators to equip their grids with digital metering and control equipment that ensures sufficient interoperability between grid operators and thus coordinated grid operation.
- The framework conditions for the smart meter rollout should be significantly simplified and the installation targets for grid operators should be raised. Effective financial incentives should be set through grid regulations to prioritise the smart meter rollout.
- In order to accelerate the flexible operation of important decentralised flexibilities such as electric vehicles or decentralised storage, it must be possible to supply such consumers directly using simplified metering equipment behind the electricity meter (split supply).

2 Annex: further data on renewables expansion in the KN2035 scenario

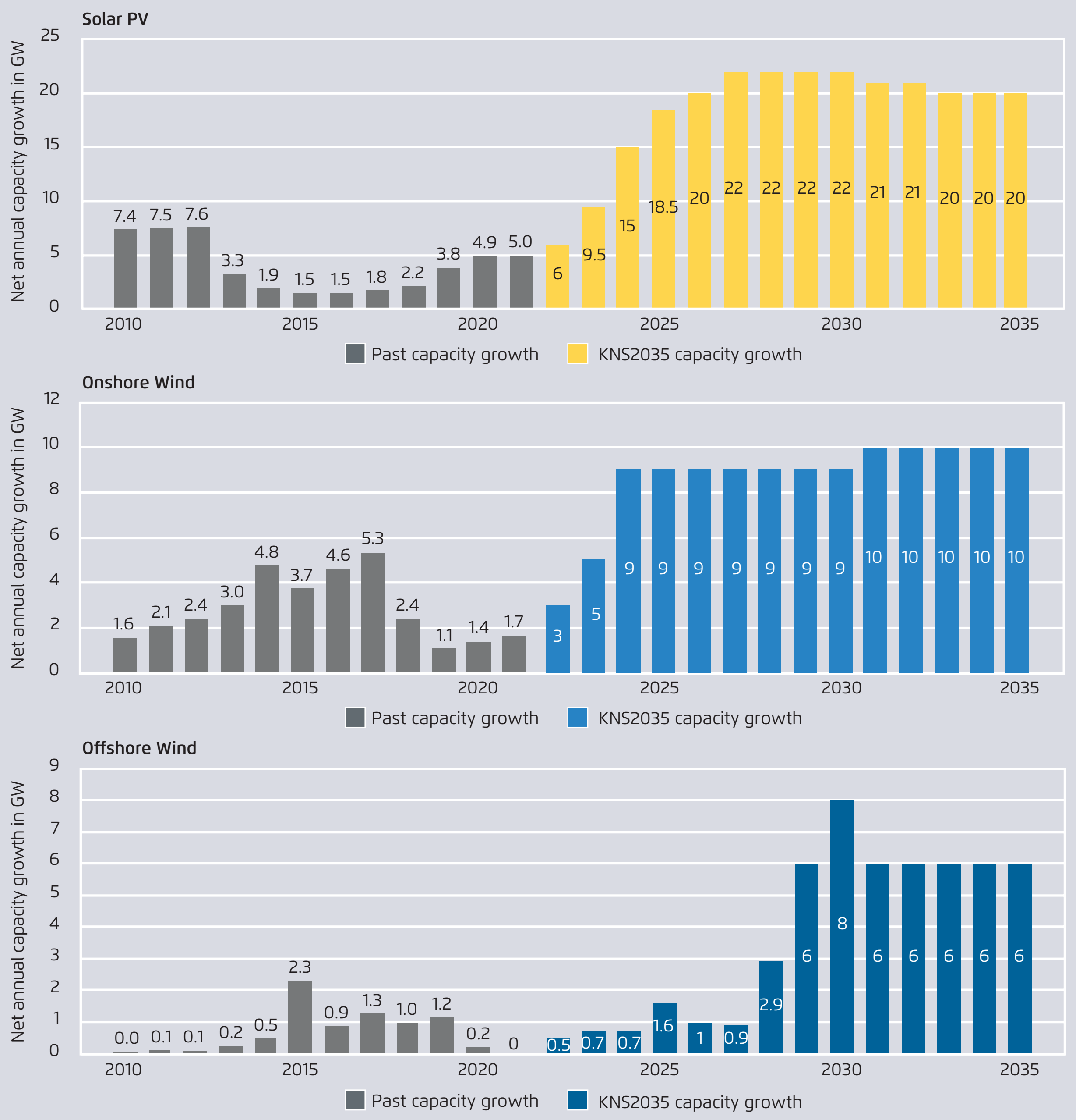
Renewable energy in the KNS2035 scenario — Figure 6



Prognos (2022)

Renewables generation has been adjusted to reflect curtailment. The figures for bioenergy include biogenic waste.

Net annual renewable capacity expansion in the KNS2035 scenario | Figure 7



Prognos (2022), AGEE Stat (2022)

Annual capacity growth in GW (actual data up to 2021)

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Agora Energiewende develops scientifically sound, politically feasible ways to ensure the success of the energy transition – in Germany, Europe and the rest of the world. The organization works independently of economic and partisan interests. Its only commitment is to climate action.

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