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Germany's electricity supply of the future

Secure grids without coal

A modern and secure network based on renewable energies

giz Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

The German Energiewende-Marathon

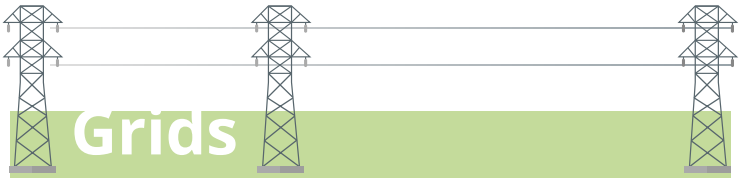
“Energiewende” is one of those words that, like “rucksack” or “kindergarten”, has become familiar in English. The transition from coal to renewable energies is a project of the century for Germany as an industrialised country in the heart of Europe. And it rightly raises many questions.

The aim of this brochure is to show how Germany is approaching its “Energiewende” and how it is safely implementing the “coal phase-out” until 2038 at the latest. We would like to explain how the country plans to expand renewable energies, where the electricity grid is being modernised and how the old nuclear reactor and coal-fired power plant sites can be used in the future.

What helps: The “Energiewende” is not a 100-metre sprint. It is a marathon that the country started in the 1990s and that will reach its goal of climate neutrality in 2045. The coal phase-out is an important interim goal on this way and we cordially invite you to accompany us on this journey.

More renewables, more security

Checkbox: Milestones on the way to a secure grid with 100 percent renewable energies

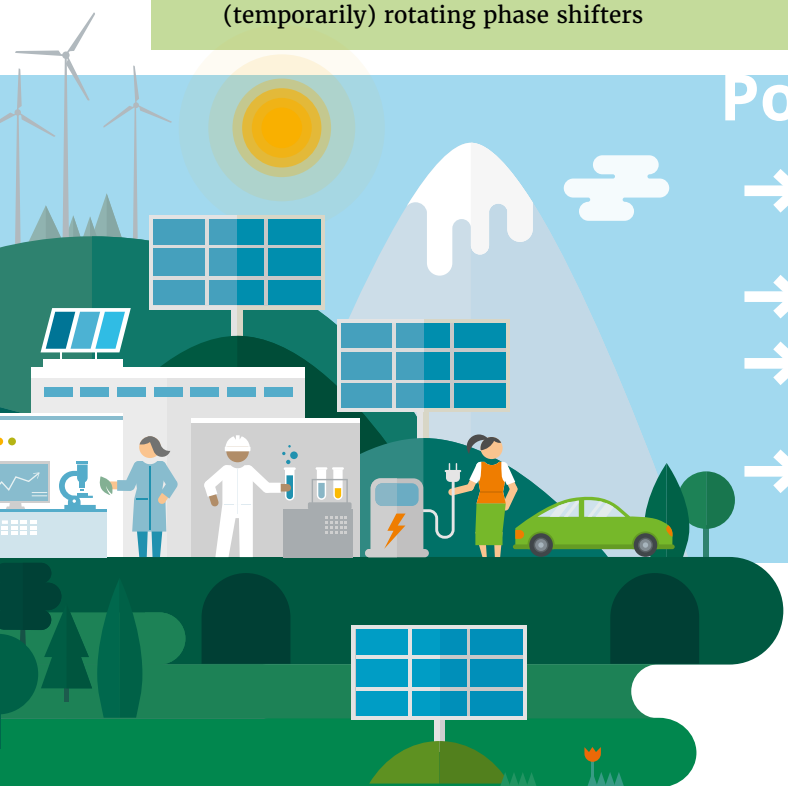


Grids

- Align grid planning with the expansion of renewables
- Strengthen power lines between renewable energy centres and industrial centres
- Expand connections with the grids of other countries (interconnection points)
- Equip grids with sensors and digitalise them for optimal utilisation
- Replace rotating masses in power plants with inverter-based generation, power electronics and (temporarily) rotating phase shifters

Power generation

- Expand renewable energies
- Aim for a good generation mix of wind, solar, hydro and biomass, depending on the natural resources of your country
- Operate remaining fossil power plants flexibly (reduce minimum load, increase load change rates, improve generation ramps)
- Use infrastructure of old coal-fired power plants (direct current landing, thermal storage, use of hydrogen, DC-converters)
- Expand conversion of surplus green electricity into hydrogen



Power market

- Create large common grids and markets, also for balancing energy and to compensate for fluctuations.
- Promote system-serving behaviour of renewables
- Incentives for reserve power plants and provision of balancing power
- Establish electricity markets through power exchanges and wholesale trading cross-sections to digital management.

From coal to the future

Already 30 years in restructuring: How Germany's electricity grid remains secure even without electricity from coal and nuclear power

On 31 March 2019, it was finally over. In the control room of the northern German coal-fired power plant, workers, engineers and local press gathered to be present at this historic moment. "We were an important institution for the region for 48 years, eight months and one day," says the plant manager. The pain of parting is palpable. Then his engineers take the old coal-fired power plant's 345-megawatt generator off the grid, shut down the coal mills and stop the hands of the large mechanical clock in the generator hall. At 12:35 the coal-fired power plant goes off the grid. Forever.

With the shutdown of the last coal-fired power plant in Kiel, the region between the North Sea and the Baltic Sea is setting an example for what will be reality throughout Germany by 2038 at the latest and ideally by 2030: The final farewell to the hundred or so power plant units still running on lignite or hard coal today. At peak times, they once covered two-thirds of Germany's electricity demand.

Wind and sun can replace coal

But where does the electricity come from in the future? And who guarantees the safe operation of the power grid?

Kiel is the capital of Schleswig-Holstein, one of 16 German states. This state between the North Sea and the Baltic Sea has always been a pioneer of the energy transition in Germany. Enthusiastic technicians erected the first wind turbines here 30 years ago - at that time barely higher than the trees between the fields - and continued to expand renewable energies. In December 2021, the last nuclear power plant in the region was taken off the grid. But even without coal and nuclear power plants, the approximately 3,500 wind turbines, 55,000 solar panels and almost 1,000 biogas power plants in the region produce several times more electricity than is consumed in the federal state of Schleswig-Holstein.

What started in the north in the 1990s is now continuing throughout Germany. "We will generate half of Germany's electricity from domestic renewable energies such as wind energy and photovoltaics as early as 2023," says Oliver Krischer, Parliamentary State Secretary with the rank of Vice Minister in the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

The transition from coal-fired power to renewable energies is fluid: every year, a few percentage points more electricity is generated from wind and sun. According to the federal government's plans, the share will be 80 percent by 2030. The annual increase is to reach 10,000 megawatts of onshore wind, 5,000 megawatts of offshore wind and 20,000 megawatts of photovoltaics.

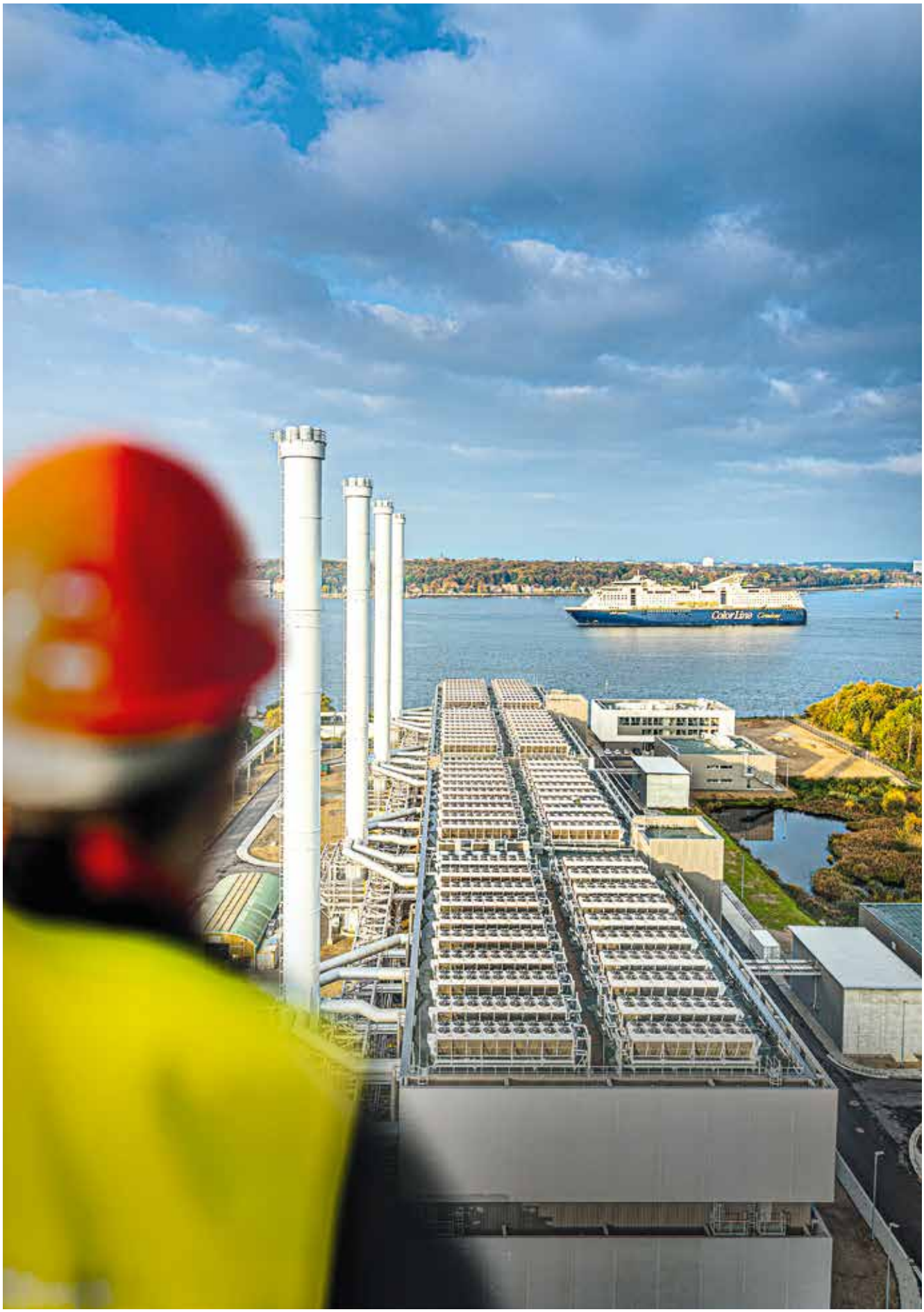
This means that the industrialised country in the heart of Europe remains what it has been for decades: an electricity surplus country that, on balance, exports more electricity in exchange with neighbouring countries than it purchases from France, Poland or Austria.

Safety first

The security of the electricity supply in Germany has always been one of the top priorities and has never been endangered by the switch from nuclear and coal to renewables. "Today, the electricity grid is more secure than ever before in our history," Krischer concludes.

This is confirmed by the figures of the Federal Network Agency (BNetzA), which is responsible for network security: while 15 years ago the network failure (medium voltage) was 20 minutes per year, this value has recently decreased to 10 minutes (see graph page 6).

This means that Germany has the lowest downtime of all industrialised nations worldwide. The reason: the switch to renewables is a process that takes decades. And as gradually as the expansion of renewables pro-



Switched: The new power plant in the city of Kiel has replaced the coal-fired power plant since November 2019. It is operated with combined heat and power and and supplies electricity and heat for the city.

ceeds, so too does the grid continue to develop. "That's why the additional costs for grid expansion remain manageable. The German electricity grid dates back in part to the times of the Second World War and needs to be modernised and adapted on an ongoing basis anyway," explains the State Secretary.

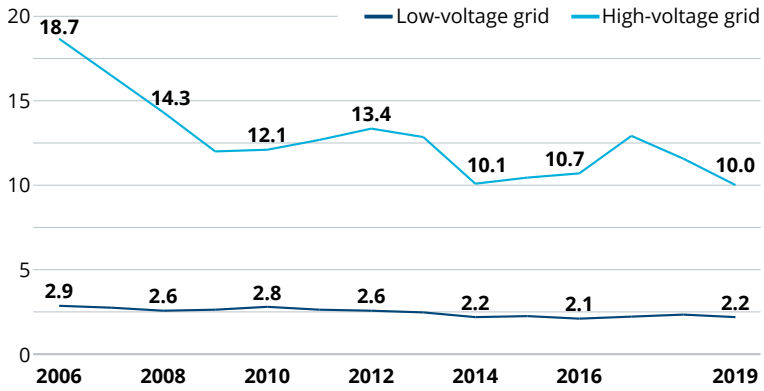
Power line expansion: the artery of the energy transition

With the erection of the first wind turbines in the 1990s, the conversion of the electricity grid in northern Germany also began: "Industry, citizens, nature conservation associations and other institutions recognised the need and the opportunity for the north. They have become an energy producer for the whole of Germany. And they were ready early on to build the necessary infrastructure for this," says Mathias Fischer. He is a spokesman for the electricity grid operator Tennet, which runs the high-voltage grid in Schleswig-Holstein.

A good electricity grid is a central prerequisite for the switch from coal and nuclear to sun, wind and water. Because when the wind blows across northern Germany and the wind turbines run at full capacity, the electricity has to flow towards the German industrial centres. That was not the case in the past: The large coal and nuclear power plants were located close to Germany's industrial regions. Today and in the future, much more electricity has to be transported from the windy north to the centre and south of the country.

Most of these changes are quite unspectacular. They hardly make it into the big news broadcasts and are more of a topic in the

More renewables, fewer interruptions



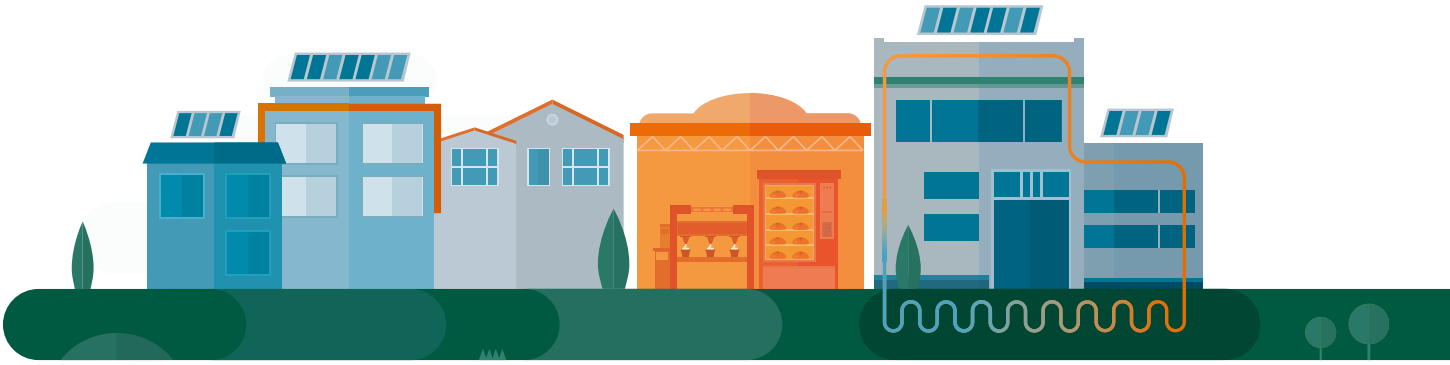
Average Power grid outage for a single houshold (SAIDI) in minutes per year (nationwide)
Source: BNetzA

specialised press: In the west of Schleswig-Holstein, Tennet has built a new 380 kV high-voltage line 150 kilometres long to collect the electricity from the thousands of wind turbines. "This has immense significance for Schleswig-Holstein as an energy transition state," says Robert Habeck. The then energy transition minister of Schleswig-Holstein is now the federal minister of economics responsible for grid expansion throughout Germany. And in 2019, another important power line was reinforced so that the lines across the river Elbe can now transport seven times as much wind power southwards. Habeck knows: "Grid expansion is the prerequisite for the energy transition to work."

To keep the lights on in northern Germany even when there is no wind, northern Germany today is connected to the neighbouring countries of Denmark, Sweden and Norway with strong high-voltage direct-current power lines. "We can get large amounts of green electricity from hydroelectric plants, especially from Norway. They help to stabilise the grid in low-wind weather conditions and provide the region with a secure supply of electricity," says Tennet spokesman Fischer. This expansion is also proceeding step by step. In total, Germany plans to build a good 1,000 kilometres of new lines in the next 15 years (see page 8: Expansion of the electricity grid). In addition, there will be technical measures such as the conversion to larger cross-sections of power cables, the increase of transformer capacities or the installation of better measuring technology in order to permanently monitor the lines and thus better utilise their capacity.

For the transition: gas and coal power in silent reserve

To ensure that all conceivable emergencies or extreme weather conditions are taken care of, the Federal Network Agency, which is responsible for safety, has had additional reserve power plants up its sleeve since 2015.



Most recently, these were mainly gas-fired power plants with a capacity of just over one gigawatt - less than half a hundredth of the total installed power plant capacity in Germany of around 230 gigawatts. In the coming decades, experts estimate that these reserve power plants will be expanded to 10 to 13 gigawatts. In order to keep costs as low as possible, various market designs are being discussed today. The idea is for electricity companies to build power plants that are operated with gas in the first few years and then converted to climate-neutral hydrogen. Refinancing should then take place through a mixture of normal electricity sales and start-up financing by the state - and cost German electricity customers as little as possible. The war in Ukraine and Germany's energy dependence on Russian may change the timetable, but not the fundamental course.

Use old coal-fired power plants!

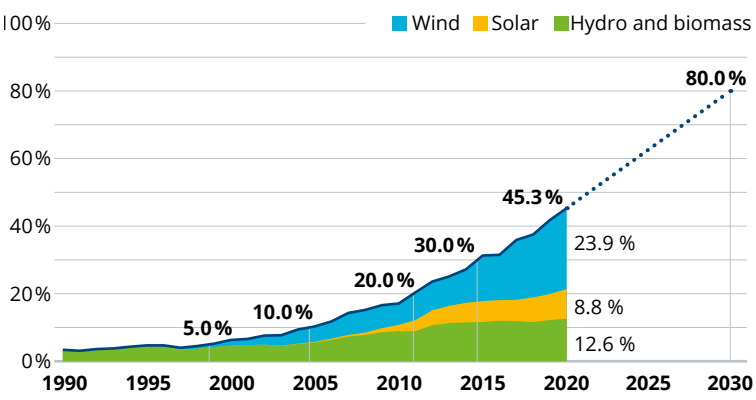
In the slow transformation of the electricity grid towards renewable energies, the old coal-fired power plants will also play a role. In Hamburg, the second largest city in Germany, a coal-fired power plant owned by Vattenfall will be converted into a production facility for green hydrogen. Where the coal boiler stands today, an electrolyser will then convert offshore wind power from the nearby North Sea into hydrogen.

At other locations, the operators want to switch from coal to gas and later to hydrogen from renewable energies. By doing so the entire infrastructure from the grid connection to the turbines can still be used. The conversion saves enormous costs and jobs can also be preserved.

So the time of the old coal-fired boilers is coming to an end forever. In Kiel, where the boiler was taken off the grid in March 2019, the coal-fired power plant has since made way for a new facility: its gas generators with combined heat and power supply electricity and heat and, thanks to their ability to start up and shut down quickly, ensure that the fluctuating renewable energies in the grid are well balanced. And when there is surplus wind power, the electricity can heat a huge heat storage tank with 30,000 cubic metres of water in an electrode boiler. The next step is to add a large seawater heat pump to the power plant. With the help of offshore wind power, this will use the heat from the sea to supply Kiel with hot water for the citizens' heating systems.

The coal phase-out has thus been achieved in Kiel. The CO2 savings of the new power plant are already 70 percent compared to coal-fired power. By 2035, the fossil gas is to be replaced by climate-neutral gas or hydrogen. But that is already another story.

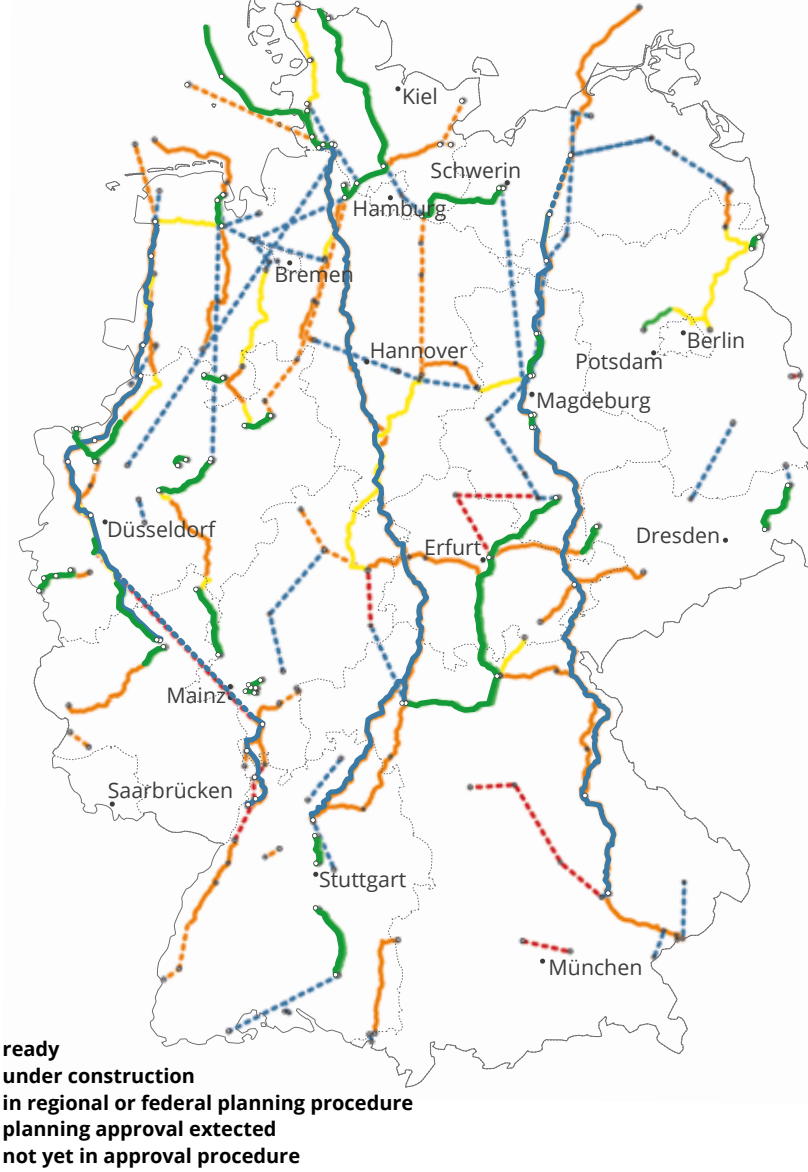
Renewables on the rise



Share of renewables in German electricity generation
Source: BNetzA

Expanding the power grid

The responsible Federal Network Agency (BNetzA) has analysed which new power lines are needed for the restructuring of the energy supply in Germany. These projects, including two particularly powerful direct current lines from north to south, are described in a separate law. The gridplan is under permanet review and will be implemented in the coming years. Of the total of more than 11,500 kilometres of power lines that are to be modernised or newly built in the coming decades, about 2,600 kilometres have been completed or are nearing completion, about 5,500 kilometres are in the approval planning stage and for 3,400 kilometres only the need has been defined. Planning takes time – a point that the federal government now wants to address.



More electricity: New power cables have multiplied the line capacity across the river Elbe.

Better networks: focus on lines

Rather than building new power lines, it is almost always cheaper to make better use of existing lines or to upgrade them. In Germany, 220 kV overhead lines are therefore often increased to a transport capacity of 380 kV. “High-temperature conductors” are used, which allow a greater current flow and expand the cross-sections of power cables. So-called overhead line management is particularly advanced. In Germany, the large power lines are allowed to heat up to a maximum of 80 °C, in some regions even only to 40 °C, when the current is passed through them. This is to prevent the warm lines from sagging too much due to their increase in length. The current flow is limited accordingly. However, this maximum voltage has been determined for warm summer days, not for cold days. With overhead line monitoring, the grid operators therefore continuously determine temperatures on site and can thus utilise the lines 20 to 30 percent more in autumn and winter. In the meantime, almost 90 percent of the 380 kV grid in Germany has been equipped with monitoring in some areas.

Mature: From tariff to market

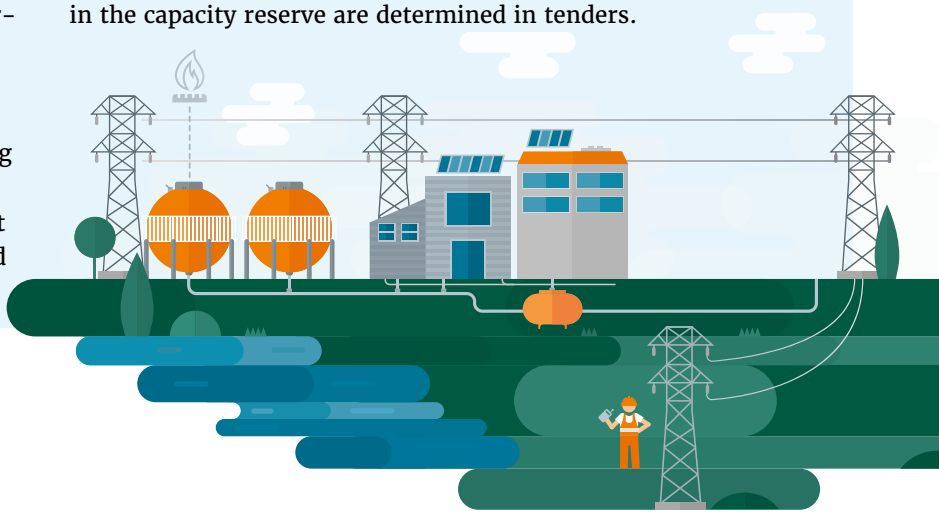
New wind power and solar plants in Germany today are financed through auctions, the sale of electricity on the stock exchange and direct power purchase agreements (PPAs). The phase of market ramp-up with a fixed feed-in tariff is largely over. The reason: electricity from wind and solar is cheaper than fossil energy, so state subsidies can be phased out.

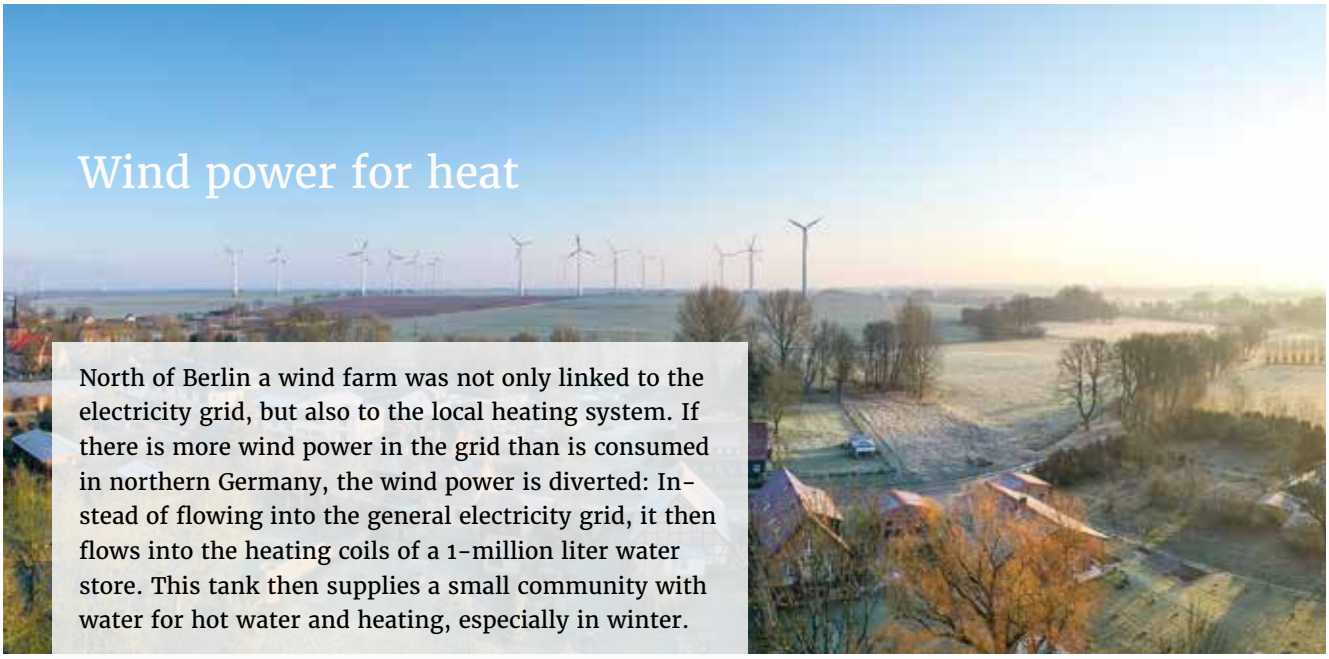
Trading green power: The European Energy Exchange (EEX) builds sustainable commodity markets in Europe.

Line construction and the provision of energy reserves, on the other hand, remain a state task. The responsible Federal Network Agency (BNetzA) monitors the further development of the electricity grid in consultation with the grid operators. It puts capacities for reserve power plants out to tender in auctions, insofar as they are needed for the secure operation of the electricity grid. The grid operators, on the other hand, purchase balancing and control energy in energy-only markets.

For emergencies: Power plants in reserve

Every electricity grid must be secured against the unexpected failure of individual lines and power plants. In Germany, there is a so-called capacity reserve for this purpose, an "ultima ratio solution that ensures security of supply even in unforeseeable and extraordinary extreme situations" - according to the responsible Federal Network Agency. For the period until 2022, mainly gas-fired power plants with a good 1000 MW are lying dormant in the background. For the period from 2022 to 2024, 2000 MW will be sought by tender. "The capacity reserve is intended to provide additional capacity in times when, despite free pricing on the wholesale market, there is insufficient supply to meet all demand," the agency says. How it continues after 2024 is determined by the experts according to technical need and in consultation with the operators of the electricity grid. The power plants in the capacity reserve are determined in tenders.



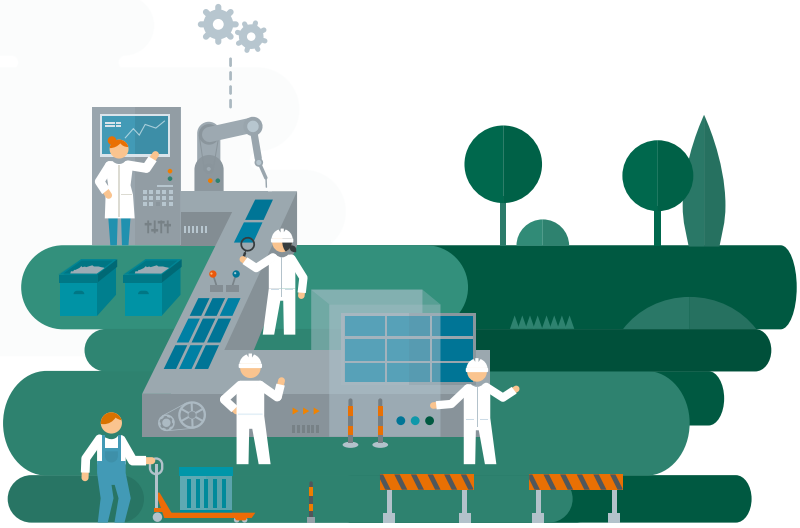


Wind power for heat

North of Berlin a wind farm was not only linked to the electricity grid, but also to the local heating system. If there is more wind power in the grid than is consumed in northern Germany, the wind power is diverted: Instead of flowing into the general electricity grid, it then flows into the heating coils of a 1-million liter water store. This tank then supplies a small community with water for hot water and heating, especially in winter.

The project has a pioneering character: there are many wind turbines in north-eastern Germany and many towns already have local heating grids. In smaller towns such grids can be laid easily and cheaply. In the future, low-cost wind power can therefore replace natural gas and promote the phase-out of fossil fuels.

Power to Heat: In the village Nechlin north of Berlin surplus wind power is converted into hot water.



Machine builders test demand side management

In the Berlin plants of the Siemens Group, engineers are testing whether they can also partially align their plants such as kilns or machines for balancing rotating bodies with the supply of renewable electricity.

Dynamo plant, measuring device plant, switchgear plant, gas turbine plant: Siemens has always operated large factories in Berlin. Now it has examined 29 energy-intensive processes there, from air conditioning to kilns, to see to what extent they are flexible in terms of time. The Siemens plants should benefit from favourable electricity prices and at the same time Siemens helps to better integrate renewable energies into the electricity system.

The investigations have shown that firing processes in the factories in particular are among the best candidates for “flexible loads”. A kiln draws a power of around 100 kilowatts and has an energy demand per firing process of 2000 kilowatt hours - that is almost as much as a Berlin household consumes per year. And firing processes can often be postponed by a few hours.

This saves money for Siemens. And it helps the grid operator to balance out the fluctuating power generation from wind and sun.

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