Energy Policy Review

Germany 2025

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Table of contents

Executive summary

Germany is at an important inflection point in its energy transition. As one era of its energy history draws to a close, another is coming clearly into view – the move away from nuclear, coal and Russian natural gas contrasted by the transition towards renewables, low-emissions hydrogen, heat pumps and electric vehicles (EVs). While the world has been buffeted by geopolitical and geoeconomic challenges in recent years, Germany has worked hard to accelerate its clean energy transition. This report seeks to provide Germany with timely advice on how it can progress towards its energy and climate goals, including in three key focus areas: 1) optimising electricity system operation; 2) decarbonising heating in buildings; and 3) expanding the role of hydrogen in the energy system. It emphasises the need for long-term policy stability, targeted demand creation, infrastructure development, integrated planning and streamlined permitting to successfully advance Germany's energy transition.

Germany's transition is crucial not only to meet its climate goals, but also for its energy security and economic competitiveness. It is targeting a 65% reduction in greenhouse gas (GHG) emissions by 2030 (from 1990 levels) and climate neutrality by 2045, with the long-standing *Energiewende* strategy guiding the evolution of its energy system. While this has supported a surge in renewables-based electricity generation, which will need to both continue and grow, more work lies ahead to decarbonise end-use sectors, such as transport, industry and buildings. Existing strategies and supportive policy measures in these sectors will need to be matched by a strong focus on effective, cost-efficient implementation. Given that German consumers pay among the highest electricity prices in Europe, policy developments will need to also be seen through an affordability and competitiveness lens, including by ensuring that the distributional impacts are well understood and that proactive measures are taken to manage the costs of transition measures. To ensure public support for the transition, the government should also clearly communicate costs, benefits and timelines.

Germany should prioritise actions that optimise the efficiency and resilience of its growing electricity system, such as smart meters, grids, storage and locational pricing. As it seeks to achieve 80% renewable energy in power consumption by 2030, faster smart meter rollout can help unlock the flexibility latent within "behind-the-meter" assets (solar panels, heat pumps, EVs). Actions could also be taken to facilitate distribution grid upgrades, enable access to and use of smart meter data, and potentially allow smart meters to control distributed solar photovoltaic (PV) supply. Germany should also jump-start an expansion of large-scale storage in optimal locations, including by fast tracking the implementation of measures in its electricity storage strategy and accelerating grid connections for projects. Routes for action could include the expansion of capacity in existing programmes (frequency response and services markets, grid booster initiative, etc.) and the adoption of new, utility-scale storage tenders targeting optimal locations. Such efforts should be complemented by clearer locational signals to improve system operation and reduce the need for new grids, as the efficient use of existing grid infrastructure is crucial. Supportive actions could include ensuring that new grid connections are in optimal grid locations (now and in the future), and that locational signals are part of future support rounds for generation, storage and electrolysers.

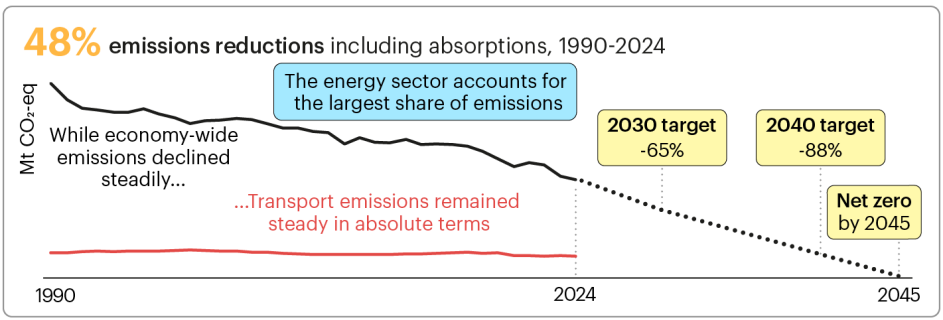
The transport sector must shift into high gear if it is to help drive Germany's energy and economic transition. Transport is the largest source of energy end-use emissions and has registered only modest reductions in recent years. A broad approach is required that incorporates all clean fuels and technologies, including greater use of public transport. Long-term investments to upgrade public transport infrastructure can support modal shifts away from road transport (which accounts for 95% of total transport emissions). There is also considerable potential to adopt policies that boost EV uptake. Options include a bonus-malus tax structure that incentivises low-emissions vehicle purchases, specific measures targeting leased and company cars (the largest share in the German market), faster deployment of charging infrastructure, ensuring even treatment of compliance options in Germany's GHG quota policy, and improving co-ordination across relevant ministries. Germany's incredible transport heritage and manufacturing base has the potential to be a distinguishing asset, but this hinges on well-designed transition measures that support its competitiveness in the clean energy economy.

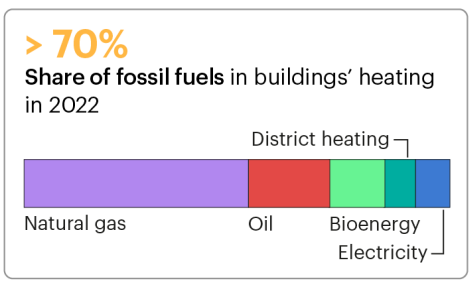
A clear vision for transitioning Germany's building stock must be coupled with consistent communication and dependable policy signals. The Building Energy Act provides a clear, long-term legal framework that sets targets and timelines for renewables-based heating systems. This must be coupled with equally clear policy signals that electricity (i.e. decentralised heat pumps) and decarbonised district heating paired with increased energy efficiency will be the primary options to

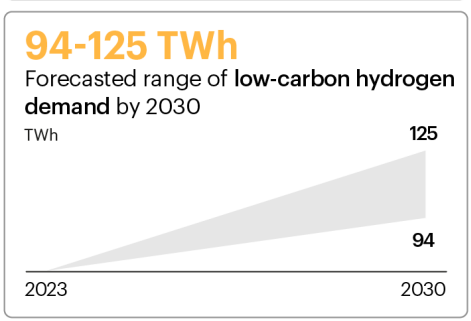
decarbonise heating in buildings. There should be support for energy efficiency upgrades and the deployment of heat pumps, as well as backing the role of energy advisors to assist homeowners. The Heat Planning Act is also a significant positive step, requiring municipalities to present plans to make local heating infrastructure climate-neutral. It is important to support the timely development of these plans, ensuring that all levels of government have the resources needed to implement them. There may also be positive opportunities to foster regional co-ordination, align heat planning with other energy system planning, and use the plans as the basis for large-scale technology procurement. Proactive, fact-based communication to consumers should explain the need to accelerate the decarbonisation of buildings, that energy efficiency and electrification is the most viable solution pathway, the business case for such investments, and the support measures available to facilitate adoption.

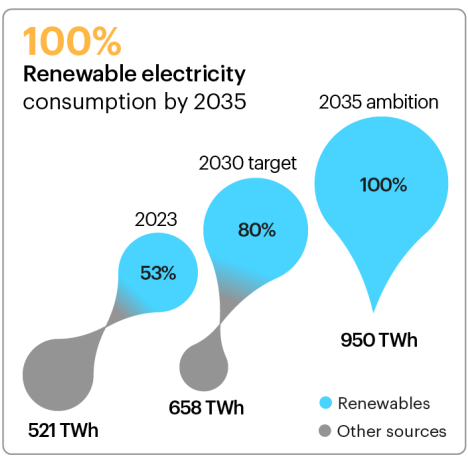
Germany has high ambitions for low-emissions hydrogen to transform the industrial heart of its economy. A comprehensive hydrogen strategy exists, prioritising hydrogen use in industries where direct electrification is challenging. Ambitious supply and demand goals are accompanied by plans for extensive domestic infrastructure buildout and international co-operation to help grow a global green hydrogen economy. Despite this, final investment decisions are lagging due to concerns over supply, affordability and the lack of off-taker commitments. There is a need to stimulate low-emissions hydrogen demand, using levers such as public procurement, targeted carbon contracts for difference and green materials standards, among others. An integrated planning approach for hydrogen, natural gas and electricity infrastructure can maximise synergies and de-risk investments, such as by realising opportunities to repurpose gas pipelines. Toward this end, the 2024 System Development Strategy aligns system planning across the electricity, natural gas and hydrogen networks.

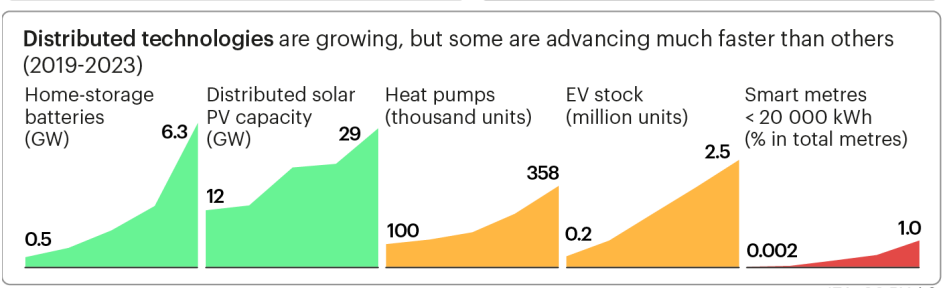
Overall, Germany's energy transition can present an immense opportunity if the right policy choices are made. As a technological and industrial leader, Germany is well-placed to realise these opportunities if it can optimise the operation of its energy system; increase citizen acceptance for the energy transition (including through clear, regular communications); and ensure a steady, long-term policy and regulatory environment that help accelerate investments. Equally important will be due consideration to energy costs, especially electricity, as electrification becomes a centrepiece of the energy transition. Looking forward, regular reviews of progress and corrective actions will be important to help Germany meet its goals.











Policy recommendations for Germany

1
Ensure long-term policy and regulatory stability to support a secure and affordable clean energy transition as the key engine of German economic growth.

2
Significantly ramp up efforts to decarbonise the transport sector.

3
Clarify the role that natural gas is expected to play through the energy transition.

4
Prioritise actions to lower electricity retail prices.

5
Create clearer locational signals to improve system operation and reduce the need for new grids.

6
Hasten the smart meter rollout to unlock the enormous potential of demand-side flexibility and distributed generation.

7
Jump-start the expansion of large-scale storage in optimal locations.

8
Co-ordinate and advance municipal heat planning to enhance the value for stakeholders.

9
Send clear signals that heat pumps and district heating paired with energy efficiency will be the primary option to decarbonise heating in buildings.

10
Focus efforts to stimulate targeted, low -emissions hydrogen demand.

Energy policy landscape

Germany has made impressive strides in its energy transition in recent years. Its *Energiewende* strategy to move away from fossil fuels and nuclear toward a renewables-based energy system has already shown results. Renewable electricity has surged in the past decade and all nuclear generation ceased as of 2023.

Moreover, despite an historically heavy dependence on energy supplies from the Russian Federation (hereafter, “Russia”), Germany has managed to significantly wind down its imports of Russian oil and gas. In line with European Union (EU) policy, Germany, in its so-called “Easter Package”, has placed a more rapid shift to renewables at the cornerstone of its energy strategy. This will help to achieve its climate objectives and mitigate energy security risks stemming from a heavy dependence on imported fossil fuels.

Nonetheless, the changes in Germany’s energy system did not come without their challenges. In particular, as the energy crisis drove an increase in energy prices, German industry bore heavy costs, resulting in stalled industrial output and a growing number of companies considering to relocate abroad. Likewise, German households face some of the highest energy costs in Europe, especially for electricity. As German climate targets necessitate accelerating action to cut emissions from the energy sector, addressing competitiveness and affordability challenges will take on outsized importance, to maintain support for the energy transition itself and to ensure a fair distribution of the benefits and costs from the transition. Furthermore, a 2023 constitutional court ruling on climate spending in the context of debt limits could hamstring the government’s ability to offer financial support for energy transition measures.

The goal of a climate-neutral energy system is also accompanied by challenges regarding system stability and the safe operation of the energy system. The federal government's "System Stability Roadmap" provides the first structured roadmap for achieving a secure and resilient operation of the energy system with 100% renewable energy sources. To ensure integrated planning of energy infrastructure, the System Development Strategy details the envisioned transition to a climate-neutral energy system by 2045.

Notwithstanding the challenges, Germany is well-positioned to advance its energy transition in the coming years. It has a legally robust climate framework, effective support mechanisms for renewable energy, and clear strategies for areas such as decarbonisation of heating and the development of a hydrogen economy. To leverage its advantages as an industrial leader, Germany must identify ways to optimise the operation of its energy system, increase citizen acceptance for the energy transition, and ensure a supportive policy and regulatory environment to accelerate energy transition investments in a cost-effective way.

Climate and energy strategy

Climate trends and targets

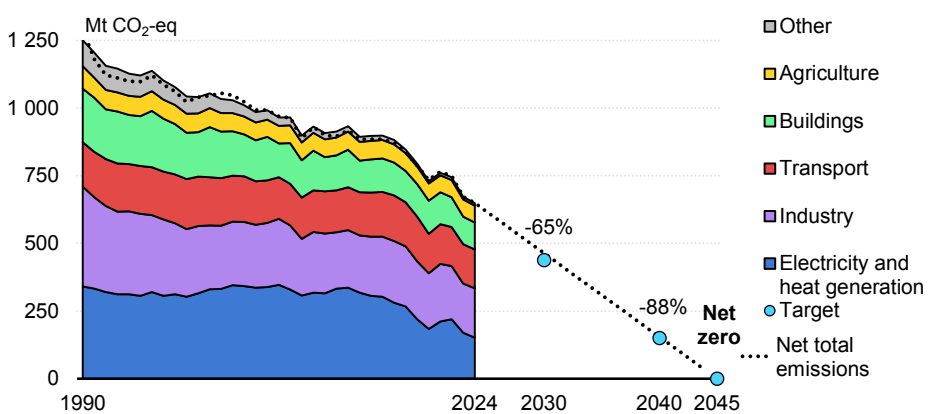
Under both the Paris Agreement and its Federal Climate Change Act, Germany committed to cutting GHG emissions by at least 65% below 1990 levels by 2030 and 88% by 2040, on the path to achieving GHG neutrality by 2045. As of 2024, emissions had fallen 48% from 1990 levels, indicating that steeper cuts are needed to meet the targets.

As a member of the European Union, Germany is subject to EU climate policy and regulation. Large combustion facilities in the power and industry sectors are part of the EU Emissions Trading System (ETS), whereas non-ETS emissions (transport, buildings, agriculture and waste) are subject to binding national GHG targets under the EU Effort Sharing Regulation (ESR). For the European Union as a whole, the ETS target is to reduce GHG emissions by 62% from 2005 levels by 2030, while the ESR target is to reduce emissions by 40% from 2005 levels by 2030. Under the ESR, Germany's updated national target is to reduce emissions by 50% from 2005 levels by 2030.

According to the Federal Environmental Agency, Germany's emissions are below its permitted annual emissions, reaching 649 Mt CO_2-eq in 2024. The generation of electricity and heat contributed 23% to GHG emissions in Germany. This significant contribution is primarily due to the use of coal and natural gas in electricity generation. Although the highest energy demand among end-use sectors is the buildings sector, the transport sector is a larger contributor to GHG emissions, responsible for 22% of emissions, due to its reliance on oil products. The buildings sector accounted for 15% of total GHG emissions, while the industrial sector contributed the biggest share, 28% in 2024.

GHG emissions decreased by 3% from 2023 to 2024. In the electricity and heating sector, GHG emissions in 2024 fell by 11% compared to the previous year, mainly due to a significant decline in coal-fired power generation, enabled by the steady expansion of wind and solar power and increased electricity imports. Industry's emissions remained stable in 2024 compared to the previous year. The recent decline of industry emissions was primarily driven by reduced output due to higher manufacturing costs.

Greenhouse gas emissions and targets in Germany, 1990-2024



Note: LULUCF = land use, land-use change and forestry. Data for 2024 are provisional.

Sources: IEA analysis based on UNFCCC (2023); Germany, Federal Environmental Agency (2025), Greenhouse gas emissions (Accessed 21 March 2025).

In the buildings sector, 2024 emissions fell by 2.4% to approximately 100 Mt CO_2-eq. This reduction was aided by higher consumer prices and mild winter weather. In the transport sector, approximately 144 Mt CO_2-eq were emitted in 2024 (-1.5% compared to 2023).

The latest 2024 projection data from the Federal Environment Agency indicates that 2030 climate targets are within reach for the first time (the 2023 forecast, in contrast, estimated an emissions gap). On a sectoral basis, the report found that the electricity and heat, agricultural, and waste sectors would overachieve, while the transport sector would exceed its emissions budget by 180 Mt CO_2-eq and the buildings sector by 32 Mt CO_2-eq (cumulative for the period 2021-30). This would mean that Germany is not on track to meet its EU ESR targets for 2030.

National targets for energy and climate change in Germany

	2023		2030	2040	2045
	Status	Base year	Targets		
Total GHG emissions	-46%	1990	-65%	-88%	Net zero
Non-ETS GHG emissions		2005	-50%		
Share of renewables in gross final energy consumption	21.6%		42.5%		
Share of renewables in gross electricity consumption	52.5%		80%		
Energy efficiency (TFEC reduction)	-14%	2008	-26.5%		

Note: TFEC = Total final energy consumption.

Sources: IEA analysis based on UNFCCC (2023); European Commission (2024); Germany - Final updated NECP 2021-2030; Eurostat (2024); Germany, Federal Ministry for Economic Affairs and Climate Action (2024), Time series on the development of renewable energies in Germany.

Climate policy framework

The Federal Climate Change Act is a central pillar of Germany's national climate change policy, legally enshrining the country's climate targets, including the goal of GHG neutrality by 2045. The government undertook a revision to the Climate Change Act in 2024 that requires verification of compliance with climate targets on an aggregate rather than a sectoral basis. The Climate Change Act sets the total annual emissions budgets for each year from 2020 to 2030. Shortfalls or surpluses of the annual emissions budgets are offset evenly against the remaining annual emissions budgets until the next target year (2030 and 2040). The Climate Change Act also calls for the government to adopt a climate action programme within 12 months of the start of a new legislative term.

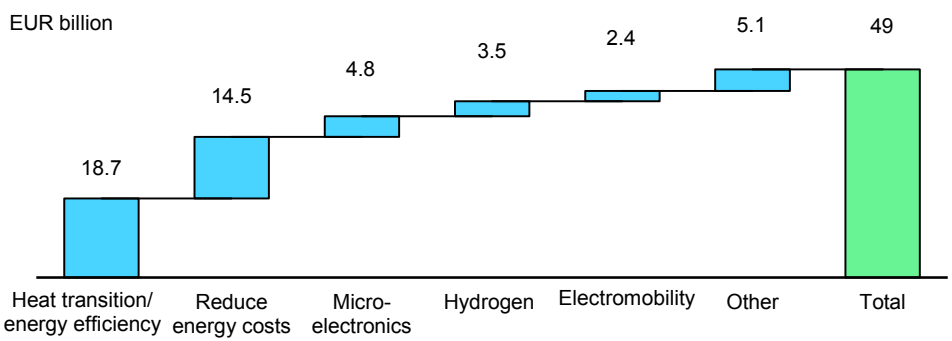
The 2023 Climate Action Programme outlines specific measures and actions across various sectors – such as energy, transport, buildings and agriculture – to meet the emissions reduction targets set by the Act. The programme also identifies funding and financial mechanisms to support implementation of these measures. Many initiatives within the current programme have already been implemented, including the Germany Ticket public transport measure, the CO_2-dependent truck toll, accelerated procedures and designated areas for renewable energy expansion, and subsidies for energy-efficient construction and renovation.

Germany's Council of Experts on Climate Change has statutory authority to ensure that Germany is on track to meet its climate targets by analysing emissions and projection data. If it finds that projections for two consecutive years point to a failure to meet the sum of annual emissions budgets to 2030, the government is required to adopt corrective measures to ensure compliance with the total emissions budgets. In a special report from June 2024, the Council found that Germany is not on track to meet the sum of annual emissions budgets to 2030 and that the Federal Environment Agency was likely underestimating emissions, especially noting the impacts of cuts to the Climate and Transformation Fund as well as changing price expectations for natural gas and EU ETS allowances. If the Council's 2025 study also finds that the 2030 target will be missed, the government will have to strengthen its climate measures by the end of the year. The Council represents an independent and rigorous check on the government's actions to help keep Germany on track toward its climate targets on a regular basis.

The main instrument for financing the energy transition and climate protection efforts in Germany is the Climate and Transformation Fund (KTF). The fund was recently

restructured in accordance with a 2023 ruling by the German Constitutional Court that found parts of the KTF previously violated a constitutional limit on new debt of 0.35% of annual GDP. The KTF is primarily financed by revenues from the EU ETS and the national fuel emissions trading (CO_2 pricing) system. The expenditures of the KTF were reduced by EUR 12 billion in the 2024 budget, resulting in EUR 49 billion available. Of the total EUR 49 billion, 40% is dedicated to supporting the heating sector's transition while 31% is allocated to reducing end-user energy costs (with EUR 10.7 billion earmarked for removing the renewable energy surcharge from end users and up to EUR 3.9 billion for electricity price compensation for energy-intensive industries, as climate protection aid). Other key focus areas include promoting semiconductors for digitalisation, expanding hydrogen use in industry and promoting sustainable mobility.

Budget allocation of the Climate and Transformation Fund, 2024



Source: IEA analysis based on Federal Ministry for Economic Affairs and Climate Action (2023), The Climate and Transformation Fund 2024: Creating relief, securing future investments, shaping transformation (Accessed on 31 March 2025).

Amid the 2022 energy crisis, Germany passed the so-called "Easter Package", which accelerated energy transition efforts as a means to tackle the energy crisis. The central focus of the package is to increase the role of renewables in Germany's energy system with updated targets, measures to facilitate siting and removal of the renewables surcharge on electricity prices.

Taxation and carbon pricing

Germany applies a tax on electricity as well as an energy tax, among other things, on oil products, natural gas, coal and coke products. The Electricity Duty Act as well as the Energy Duty Act offer tax relief in several areas in accordance with EU law, such as on electricity generated and consumed in a decentralised manner as well as on energy products used in electricity generation or co-generation, natural gas, and liquefied petroleum gas used as motor fuels. Heating fuels and electricity used by manufacturing industries also receive tax relief. Germany is supportive of ongoing negotiations on a revised EU Energy Tax Directive to better align taxation with climate and environmental objectives.

The Fuel Emissions Trading Act introduced a national emissions trading system for sectors not covered by the EU ETS, such as transport and heating. During an introductory phase, prices are fixed. They started at 25 EUR/t CO_2-eq in 2021, increased to 45 EUR/t CO_2-eq in 2024 and rise to 55 EUR/t CO_2-eq in 2025. After 2025, the pricing will shift to a market-based system, where prices will be determined by supply and demand within a specified price corridor. Starting in 2027, these sectors will fall under the EU ETS2 programme, a cap-and-trade scheme applied upstream on fuel suppliers.

Energy research and development

Energy research and development play a key role in Germany's energy transition strategy. In 2023, the government allocated EUR 1.5 billion to energy transition research funding, stabilising it at a higher level. The 8th Energy Research Programme for applied energy research, adopted in October 2023, guides the Federal Ministry for Economic Affairs and Climate Action's (BMWK) energy research policy toward the energy transition for the first time. The five missions that guide funding priorities are: 1) research into the energy system; 2) the heat transition; 3) the electricity transition; 4) hydrogen; and 5) the transfer of research findings into practice.

The Federal Ministry of Education and Research (BMBF) continues to support application-oriented basic research as part of the federal government's 7th Energy Research Programme. Within this framework, the BMBF co-ordinates basic research-orientated project funding for energy research as well as institutional funding for the centres of the Helmholtz Association (with the exception of the German Aerospace Center, which is funded by BMWK), the Fraunhofer Gesellschaft, the Max Planck Society and the Leibniz Association. In addition, the BMBF promotes young scientists,

academic exchange and scientific/research co-operation at the EU and international levels. The BMBF's three hydrogen flagship projects contribute to the goals of the National Hydrogen Strategy.

Skills and competencies for the energy transition

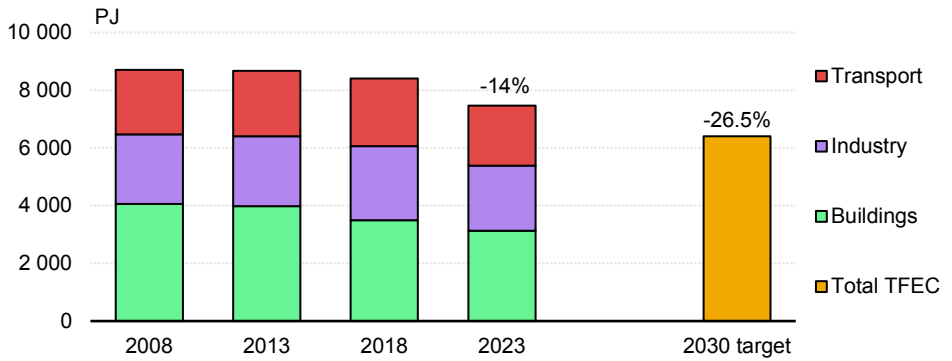
Like in all countries, Germany will need to ensure sufficient skilled workers in occupations relevant to the energy transition. Toward this goal, Germany developed a STEM (science, technology, engineering and mathematics) Action Plan 2.0 that aims to strengthen STEM education through all stages of education. It is also updating dual training regulations (workplace and school training) in vocational occupations, including for instructors. Employees that are affected by structural change in the economy, such as coal workers, can benefit from special skills retraining support. There is also special funding available for training skilled workers in specific areas important to the energy transition, such as heat pump installation.

End-use sectors

The buildings sector is the largest energy consumer, accounting for 42% of final energy consumption in 2023. Industry accounted for 30% of energy consumption while transport made up 28%. The decline in energy demand in Germany over the last decade has primarily come from the buildings sector. In 2023, total energy demand was 7 500 PJ, representing a 5% reduction compared to the previous year and 14% compared to 2008.

In the recast Energy Efficiency Directive (EED), the European Union agreed to reduce final energy consumption in the European Union as a whole by at least 11.7% compared to projections of the expected energy use in 2030, supported by indicative country targets. Since 2023, Germany has a dedicated Energy Efficiency Act that contributes to implementing the EED. It sets the "energy efficiency first" principle and establishes efficiency targets for primary and final energy consumption for 2030. The targets require a reduction of 26.5% in final energy consumption and 39.3% in primary energy consumption, both compared to 2008. In its updated National Energy and Climate Plan, however, Germany concludes that there remains a gap to achieve the 2030 target and significant additional efficiency measures are needed.

Final energy consumption in Germany by sector, 2008-2030



Notes: Industry includes manufacturing and other sectors (agriculture, construction, mining and quarrying). It does not include refinery and non-energy use (fuels that are used as raw materials and are not consumed as fuel or transformed into another fuel).

Source: IEA (2025), World Energy Balances.

Buildings

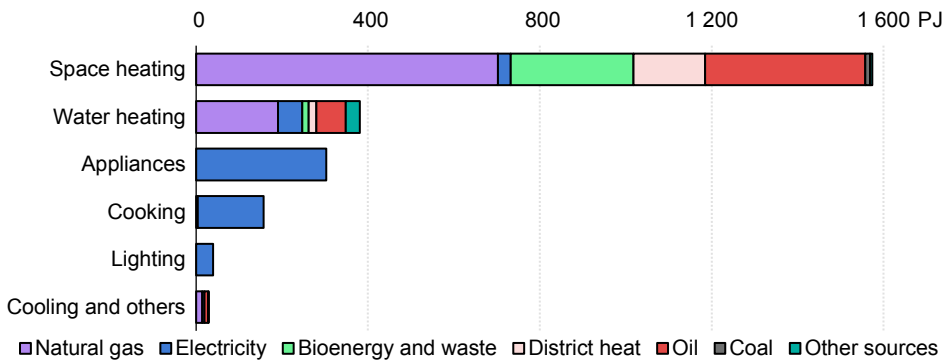
Buildings represent around 19% of direct, energy-related GHG emissions in Germany in 2022. Residential buildings accounted for 75% of the energy consumption in buildings in 2022. Within this sector, 63% of the energy is used for space heating, which still relies heavily on fossil fuels, primarily natural gas and oil.

Germany's building stock is large, with 19.4 million residential units and 2 million non-residential buildings. Moreover, its building stock is relatively old (68% built prior to 1978, before the first ordinance on thermal insulation of buildings took effect) and renovation rates are low. Ownership is heterogeneous, with a roughly even split between owner-occupied and tenancy buildings (giving it one of the lowest home ownership rates in Europe).

Decarbonising heating is crucial for achieving climate targets, and in recent years Germany has taken several steps toward this end, including with a new Building Energy Act and Heat Planning Act to provide clarity on the role for renewable energy in heating. Heat pumps and district heating are the main options for replacing gas and oil boilers. By 2030, Germany aims to have an 80% share of renewables in electricity generation and 50% renewable and recycled heat in district heating. The federal

government also provides support for investments in clean heating technologies. With measures implemented so far, Germany is making significant progress on energy efficiency and climate mitigation, reaching around 40% emissions reductions in buildings between 1990 and 2022. However, challenges remain to speed up the transition (see Focus Area 2).

Energy use in residential buildings by subsector in Germany, 2022



Source: IEA (2024), Energy End-uses and Efficiency Indicators.

Energy performance in buildings

Increasing energy efficiency in buildings helps reduce emissions, improve energy security and lower energy bills. While new buildings are covered by energy performance requirements, improving the existing building stock is often more challenging. The revised EU Energy Performance of Buildings Directive entered into force on 28 May 2024 and helps increase the rate of renovation in the European Union. The Directive defines an enhanced standard for new buildings to be zero-emission and sets binding targets to lower the average primary energy consumption of the residential building stock by 16% by 2030 compared to 2020.

Germany's Building Energy Act contains requirements for the energy quality of buildings and the creation and use of energy certificates. A 2022 amendment to the Act raised the energy performance standard for new buildings, limiting primary energy consumption in new buildings to 55% of a reference building, thereby promoting energy-efficient heat pumps over traditional boilers. The Building Energy Act also sets

a target of 65% renewable energy in the heat supply for new buildings, which also applies to existing buildings (in stages and with certain exceptions; see more in Focus Area 2).

According to the Association of Energy-Efficient Building Envelopes, however, the renovation rate in Germany is less than 1% per year, and the trend is declining sharply, calling for further action.

District heating

District heating produced from renewable energy and waste heat is one of the main options for replacing fossil fuel boilers in densely populated areas. It can be a cost- and resource-efficient solution, mainly in densely populated areas where centralised heating solutions are more practical and economical. Around 15% of Germany's apartments and 6% of residential buildings are connected to district heating networks, and in the three largest cities – Berlin, Hamburg and Munich – district heating supplies one-third of buildings. However, the adoption of district heating systems has plateaued over the past decade. Germany has no price regulation for district heating and municipalities rarely implement obligations to connect and use, which means that the technology must be competitive with other heating options in terms of cost, convenience and environmental benefits to attract consumers (see Focus Area 2).

Industry

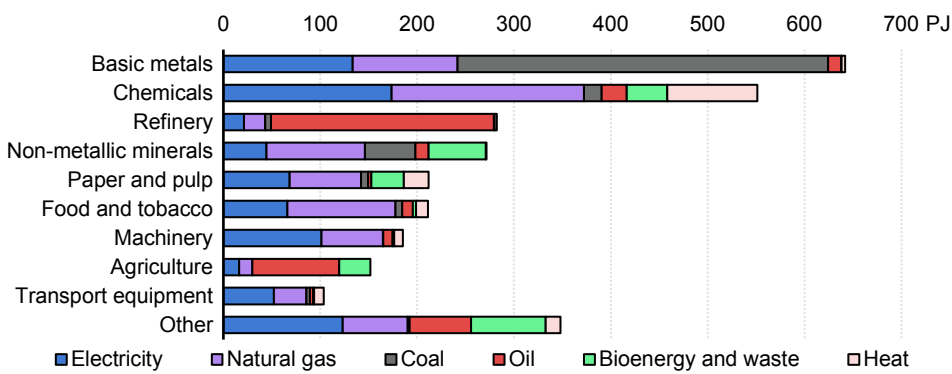
Germany has a large industrial sector, with more than a quarter of its energy consumption attributed to electricity. However, the sector remains heavily reliant on fossil fuels, which accounted for 59% of its energy use in 2022 (of which natural gas accounted for 34%). As one of Europe's leading steel producers, Germany has a well-established basic metals subsector, which is the main coal consumer in the industrial sector. The country manufactures a wide range of steel products used in construction, automotive, machinery and other industries.

Germany's chemical industry is one of the largest in the world, producing a wide range of chemicals, pharmaceuticals and biotechnology products. It is the second-largest energy consumer in Germany's industrial sector, accounting for 22% of the total energy consumption in the sector. The chemical industry primarily uses natural gas and electricity to power its operations.

The German refining industry is crucial for supplying energy and raw materials to various sectors. Emissions in this sector result from the extensive use of oil, which is processed into numerous products, including gasoline, diesel, jet fuel and various petrochemicals.

Other subsectors also contribute to high energy demand and related emissions, including the non-metallic minerals, paper, food and tobacco, and machinery industries. The non-metallic minerals industry, mainly driven by cement and glass production, is increasingly using more bioenergy to reduce emissions. In 2012, bioenergy accounted for 18% of energy use, which increased to 27% by 2022. Biofuels, such as biomass and biogas, are being used as alternative fuels in cement kilns.

Energy use in industry by subsector in Germany, 2022



Notes: This chart includes consumption in the refinery and steel industries that is not counted as final energy consumption in the figure “Final energy consumption by sector in Germany”. Non-energy used is not included.

Source: IEA (2024), Energy End-uses and Efficiency Indicators.

The EU ETS plays a crucial role in driving emissions reductions in Germany’s industrial sector. The sector is a significant participant in the EU ETS, which covers large emitters, including refineries, steel mills and chemical plants. The revised EU ETS target of 62% emissions reductions by 2030 compared to 2005 levels will further drive the need for companies to invest in emissions-reduction technologies while still maintaining competitiveness.

The Energy Efficiency Act aligns with EU energy efficiency targets and aims to reduce final energy consumption by 26.5% by 2030 compared to 2008 levels. The main measures stipulated in the Act for industry to achieve these targets include conducting regular energy audits, integrating certified energy management systems, and reporting on energy consumption and efficiency improvements.

The federal government also offers EUR 1 billion in annual funding to promote energy and resource efficiency in the commercial sector (EEW). The funding is offered along modules that cover a range of measures from energy-efficient technologies such as pumps, air compressors and electric motors to action to generate process heat from renewable energy sources and electricity.

Further funding for the decarbonisation of industry is facilitated through the Decarbonisation of Industry and Carbon Contracts for Difference (*Klimaschutzverträge*) programmes, toward which several billion euros are earmarked in the federal budget. Also, the Important Projects of Common European Interest (IPCEI) Hydrogen programme, with its budget of EUR 14 billion, plays an important role. Moreover, the Federal Funding for Industry and Climate Protection scheme (*Bundesförderung Industrie und Klimaschutz,* with EUR 3.3 billion in funding planned from the federal government) aims to enable innovative smaller and medium-sized transformation projects to be implemented, regardless of sector or technology.

To prevent carbon leakage and help German industry maintain competitiveness, the government offers several support mechanisms to address electricity costs, including an electricity price compensation for indirect carbon costs as part of the EU ETS and an electricity tax reduction for companies in the manufacturing sector. The permanent removal of the Renewable Energy Act levy on electricity also offered price relief for manufacturers.

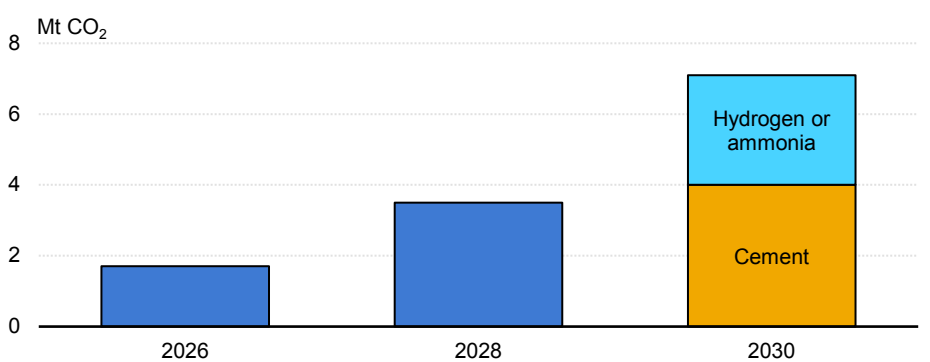
Carbon capture, utilisation and storage (CCUS)

The EU Directive on the Geological Storage of Carbon Dioxide provides a comprehensive legal framework for the environmentally safe geological storage of CO_2. This directive is implemented through national regulations, ensuring that CCUS projects comply with stringent environmental and safety standards. The Carbon Dioxide Storage Act regulates the exploration, testing and demonstration of CO_2 storage in Germany, outlining the conditions under which storage is permitted, focusing on safety, public acceptance and environmental impact. Additionally, Germany's Climate Action Plan 2050 highlights the role of CCUS in decarbonising the industrial sector, emphasising the need for innovation and research to advance these technologies.

The federal government plans to establish the economic, legal and political framework conditions for CCUS in Germany under a Carbon Management Strategy, for which key points were established in 2024. Following a broad-based stakeholder dialogue with representatives from civil society, academia and industry, the government has agreed on removing current barriers blocking the use of CCUS and focusing public funding on hard-to-abate emissions, mainly in industry.

Germany is involved in several projects and initiatives to advance CCUS technology. The EUR 23 million project ALIGN-CCUS that ended on November 2020 aimed to accelerate the rollout of CCUS by developing cost-effective and reliable CCUS solutions, with German partners like RWE and Mitsubishi-Hitachi. Another notable initiative is the Carbon2Chem project, led by a consortium of two main research institutes (Max Planck Institute for Chemical Energy Conversion and Fraunhofer Institute for Environmental, Safety and Energy Technology) and industry (Thyssenkrupp as a major player in the steel industry), which focuses on converting captured CO_2 from steel production into valuable chemicals. By combining electrolysis (Siemens Energy) and fermentation (Evonik), the Rheticus Project explores the utilisation of CO_2 and renewable energy to produce specialty chemicals through biotechnological processes (federal funding expired in 2022).

Carbon capture, utilisation and storage project pipeline in Germany, split by end use in 2030



Note: Includes all operational, under construction and planned CO_2 capture facilities with an announced capacity of more than 100 000 t per year or 1 000 t per year for direct air capture facilities.

Source: IEA (2024), CCUS Projects Explorer.

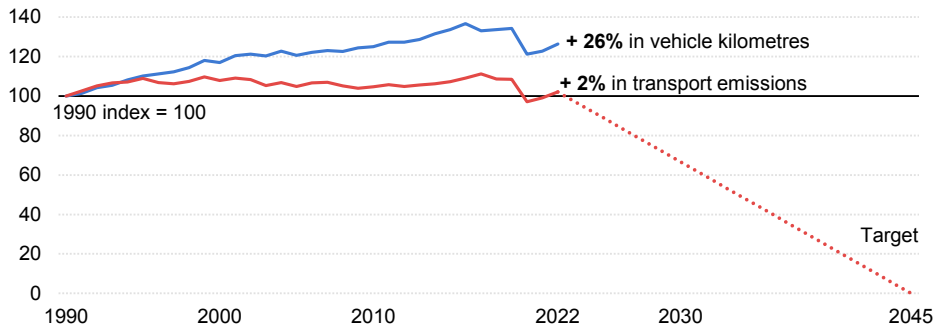
Despite advancements in CCUS technology, several challenges hinder its widespread adoption in Germany, most notably that storage is currently prohibited by law. The prohibition is due to be changed based on a forthcoming amendment to the Carbon Dioxide Storage Act, which will allow CO_2 storage in the Exclusive Economic Zone onshore (through an opt-in clause at the discretion of the federal states). Transport of CO_2 will also be regulated with legal certainty. Public acceptance remains a significant challenge, as there is scepticism regarding the safety and environmental impact of underground CO_2 storage. Building public trust through transparent communication and stakeholder engagement is crucial. Economic viability also poses a significant barrier, as the high cost of capturing and storing CO_2 makes it challenging to achieve widespread adoption. Reducing costs through technological innovation and achieving economies of scale is essential for broader implementation.

Additionally, developing infrastructure for CO_2 transport and storage requires substantial investment and planning (currently expected from private funds). Regulatory uncertainty, despite existing regulations, also necessitates ongoing policy development to provide clear guidelines and incentives for CCUS adoption.

Transport

Transport is the third-largest energy-consuming sector in Germany, accounting for approximately 20% of total energy demand. Although its energy demand is less than that of the industry and buildings sectors, its GHG emissions are higher because it remains heavily reliant on fossil fuels, with 95% of its energy demand coming from oil products. In fact, nearly a quarter of Germany's total GHG emissions come from the transport sector, which have not registered significant emissions reductions in the past few decades. The Federal Climate Action Act required that the transport sector reduce its GHG emissions to 85 Mt CO_2-eq by 2030, representing a 45% reduction from 2022 levels (recently changed to a non-binding target). Therefore, further efforts are necessary to achieve more rapid GHG reductions in the sector.

Transport sector energy consumption and emissions in Germany, 2010-2022 and target for 2045



Sources: IEA (2024), Emissions Factors and IEA (2024), Energy End-uses and Efficiency Indicators.

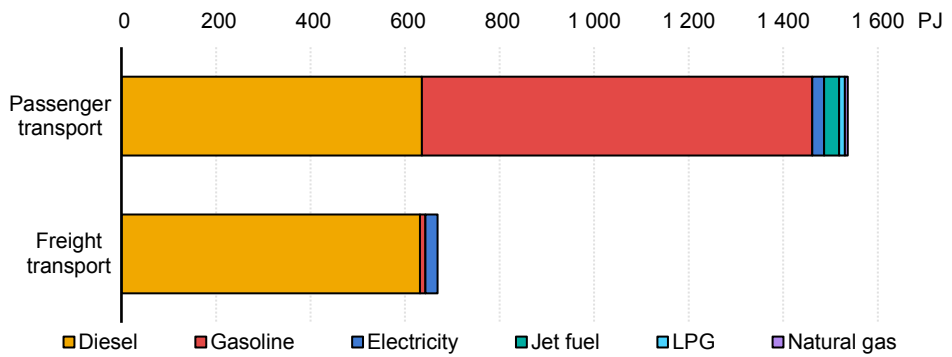
Passenger transport accounts for 70% of energy consumption in the transport sector, making it the leading GHG emitter among end uses. Cars using gasoline and diesel are the predominant mode of passenger transport in Germany. Buses used in public transport are mainly powered by diesel, while rail transport consumes most of the electricity used in passenger transport.

EU CO_2 standards for vehicles apply in Germany. For light-duty vehicles, relative to a 2020 baseline (95 g CO_2/km), new cars must see a reduction of 15% in 2025, 55% in 2030 and 100% in 2035 (when all new car sales must be zero-emissions). Heavy-duty vehicles must register reductions of 15% by 2025, 45% by 2030, 65% by 2035 and 90% by 2040.

To transpose the EU Renewable Energy Directive (RED II) requirements (minimum 29% renewables share in transport fuels or at least 14.5% reduction in GHG intensity) into national law, Germany applies a GHG quota under which fuel suppliers must cut the GHG emissions of their fuels. In 2020, fuel suppliers were required to reduce emissions by 6% (from 2010), rising to 9.35% in 2024 and 25% in 2030. The quota can be met with sustainable biofuels, renewable fuels of non-biological origin (RFNBOs) and electricity. The programme includes multiplier effects for certain compliance pathways, such as a triple effect for using RFNBOs and a quadruple impact for electricity.

Decarbonising passenger transport is a critical part of Germany's overall energy transition strategy, with EVs playing a key role. In 2023, the share of EVs in Germany's vehicle stock was 5.4%, higher than the European median and countries like France (4% share). Other European countries, such as Norway with 29% of the total stock, Sweden with 11% and Belgium with 8.2%, are experiencing higher EV penetration.

Energy consumption in transport by fuel in Germany, 2022



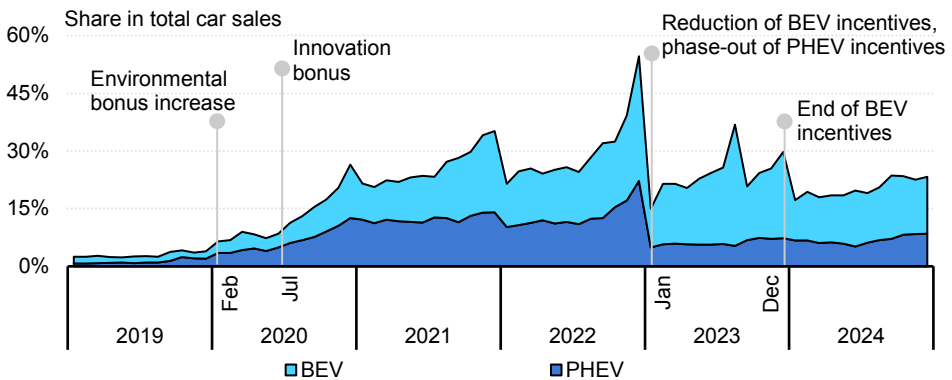
Source: IEA (2024), Energy End-uses and Efficiency Indicators.

In Germany, EVs account for around 24% of sales. At the beginning of 2020, EV sales started to rise, primarily driven by an increase in the environmental bonus, designed to promote EV adoption. The programme offered up to EUR 4 500 for EV purchases, which supported the deployment of an estimated 2.1 million EVs since 2016 (at a cost of EUR 10 billion). The policy shift boosted the share of EV sales from 3% in 2019 to 14% in 2020. Sustained policy support from the government contributed to EV sales growth in subsequent years, peaking at 31% of total car sales in 2022.

However, since the subsidy programme ended, the trend has slowed down. The government's announcement of the phase-out of incentives for plug-in hybrid electric and a reduction of incentives for battery electric vehicles starting on 1 January 2023 created a pull-forward effect. This led to a rush of purchases before the incentives were reduced, and a subsequent decline in market penetration in 2023. In December

2023, EV purchase subsidies were terminated entirely, leading to a decline in sales in early 2024. As a result, the government's target to put 15 million EVs on the road by 2030 could be challenged.

Monthly electric vehicle sales share by powertrain type in Germany, 2019-2024



Source: IEA analysis based on European Commission, European Alternative Fuels Observatory (2025), Germany (Accessed: 14 February 2025).

The development of a comprehensive, accessible charging infrastructure is vital for successful EV adoption. Germany's infrastructure is lagging the European median and other leading European countries. The 2023 Climate Protection Programme outlines measures to ensure the necessary deployment of charging points to meet the government's targets, such as a legal requirement for grid operators to expand grids for the deployment of charging points and unlocking funding for municipalities. Implementing these measures and monitoring their effectiveness is crucial to making necessary adjustments and facilitating the penetration of EVs.

The government put forward a plan to address charging infrastructure for EVs. The 2023 Charging Infrastructure Master Plan II set out the timetable for expanding charging infrastructure over the next few years. It comprises 68 measures across funding, empowering communities, universal availability, integration into the power grid, charging at buildings and heavy commercial vehicles. This Plan was designed to close the gap between electric mobility and power grids, expanding the charging infrastructure for heavy commercial vehicles and mobilising private investments.

Alongside the Master Plan for charging infrastructure, the government also has an explicit strategy for commercial vehicles. The Overall Approach to Climate-Friendly Commercial Vehicles shows how measures can be implemented in a targeted manner. As a result, the co-funding of battery and fuel cell electric commercial vehicles has been undertaken. Additionally, a tender for construction and operation of the fast-charging infrastructure for heavy-duty vehicles officially started in September 2024. The initial network will comprise around 350 locations with 4 200 charging points along motorways.

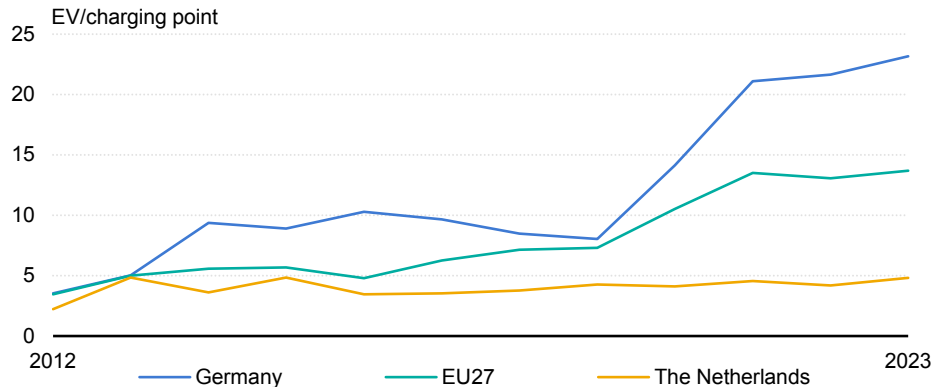
Finally, rail and public transport also offer considerable emissions reduction potential for passenger transport. Germany has made progress since the last IEA Energy Policy Review in upgrading its rail infrastructure and promoting more public transport. Notably, the introduction in 2023 of the "Deutschlandticket", which set a EUR 49 introductory price (increasing to EUR 58 from 2025) for a monthly public transport ticket that applies throughout Germany, has proven popular (up to about 13 million users per month). However, results continue to lag potential as rail and public transport often remain costlier and less convenient from a consumer perspective. As such, additional solutions to promote rail over road and air transport can be beneficial, drawing on successful measures in other countries.

The Federal Ministry for Digital and Transport also promotes cycling and walking with various funding and financing programmes, including an increased budget allocation in the 20th legislative period of up to EUR 2.91 billion by 2030 for the promotion of cycling.

Freight transport is primarily dominated by diesel trucks. More sustainable options, such as rail, offer an energy-efficient alternative and account for most of the electricity demand in this subsector. According to the 2023 Climate Protection Programme, the government aims to increase rail's share of freight transport to 25% by 2030. In addition, Germany uses its extensive river network to transport heavy goods and bulk materials by shipping, offering a lower energy intensity option, albeit still reliant on heavy fuel oil and diesel.

One of the challenges in decarbonising heavy transport is technological development. Battery technology for electric trucks is evolving, and the first hydrogen fuel cell trucks are being tested in the market. Therefore, it is crucial to plan for a long-term electric charging network and for the eventual role that hydrogen is expected to play.

Ratio of electric vehicles per charging point, 2012-2023



Source: IEA (2024), Global EV Data Explorer.

Germany could also take greater advantage of the emissions reduction potential that sustainable biofuels can bring to its transport sector. Sustainable biofuels can play a particularly important role in decarbonising harder-to-abate transport sectors such as trucking, shipping and aviation, but have also proven to hold considerable potential to lower emissions from light-duty vehicles in the near term before electrification becomes more mainstream. In particular, sustainable biofuels could bring cost advantages relative to more expensive options such as e-fuels. Meanwhile, electric trucks are gaining momentum globally, led by the People's Republic of China (hereafter, "China"), and EU CO_2 standards for heavy-duty trucks targeting a 90% emissions reduction by 2040 will further support growth in coming decades. In Germany, as of April 2024, electric vehicles accounted for 2.1% of the commercial truck fleet.

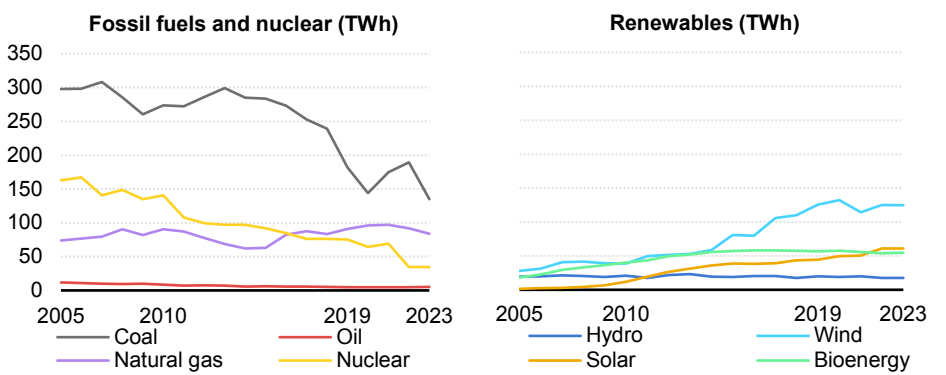
Electricity

Despite significant growth in renewables, the German electricity system remains reliant on fossil fuels. Renewable electricity generation has increased substantially in the past decade, with wind growing by 137% and solar by 95% between 2013 and 2023. By 2023, renewables accounted for 52.5% of gross electricity consumption and reached 54% in 2024. However, fossil fuels still contributed to nearly half of electricity generation in 2023, with coal making up 30% and natural gas 16%. Nuclear

energy accounted for 6% of electricity generation in 2022, but the German nuclear fleet was completely shut down in 2023.

Continued reliance on fossil fuels made electricity and heat generation the largest contributor to energy-related GHG emissions in Germany, accounting for 39% in 2022. Decarbonising electricity is, therefore, crucial for Germany to achieve its climate targets. While Germany has a plan to exit from coal no later than 2038, natural gas plants are expected to play a continued role in the power sector. A previously planned Power Plant Strategy, which aimed to hold auctions for 12.5 GW of new hydrogen-fired and natural gas-fired plants that could later (2035-40) be converted to run on hydrogen, was set aside in November 2024. However, the government still plans to implement a capacity mechanism by 2028 to support additional dispatchable capacity, including power plants, storage and demand response.

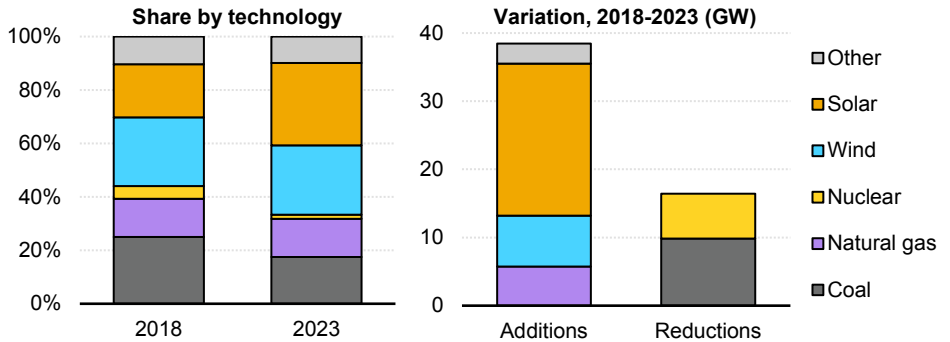
Electricity generation by fuel in Germany, 2005-2023



Sources: IEA (2025), World Energy Balances.

Electricity generation capacity in Germany increased by 45% between 2013 and 2023, driven primarily by a significant expansion in renewable energy. However, due to lower utilisation rates over the period, total generation has been relatively steady. During this decade, wind capacity grew by 36 GW and solar capacity increased by 46 GW. This growth was largely driven by two key factors: 1) the need to compensate for the loss of nuclear energy; and 2) policy support for renewable technologies.

Electricity capacity additions by technology in Germany, 2018-2023

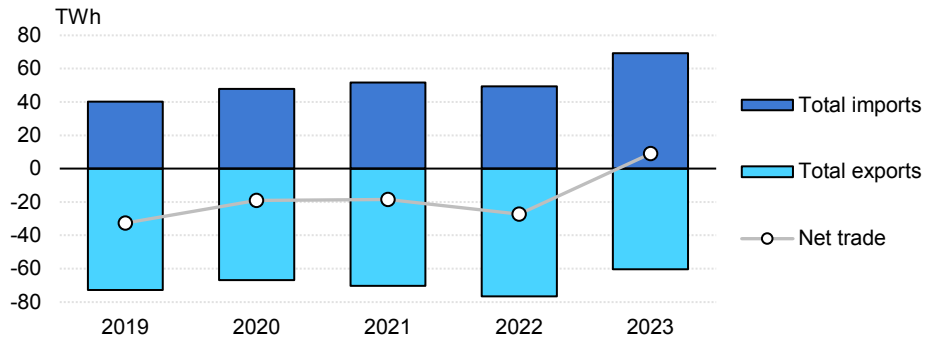


Source: IEA (2025), Electricity Information.

Germany is located in the centre of the European electricity market and therefore well-connected with its neighbours, including Austria, Belgium, Czechia, Denmark, France, Luxembourg, the Netherlands, Poland, Sweden and Switzerland. Recent additional projects include NordLink (1.4 GW capacity), which became operational in 2021, connecting Germany with Norway's system. The NeuConnect Interconnector (1.4 GW of capacity) between Germany and the United Kingdom is due to come online in 2028.

Germany became a net importer of electricity in 2023. Lower electricity generation costs in its partner countries, especially the Nordic countries (which are less reliant on gas-fired generation), along with high carbon pricing under the EU ETS helped Germany to significantly increase its imports compared to previous years. This trend was further influenced by the nuclear phase-out and ongoing phase-down of coal plants, which lowered domestic electricity generation relative to demand. The situation highlights the increasing importance of the European electricity market for Germany through the energy transition. Traditionally, Germany's main export markets are Austria, Czechia and Poland, while its top importers are Austria, Czechia, France.

Electricity trade in Germany, 2019-2023



Source: IEA (2025), Electricity Information.

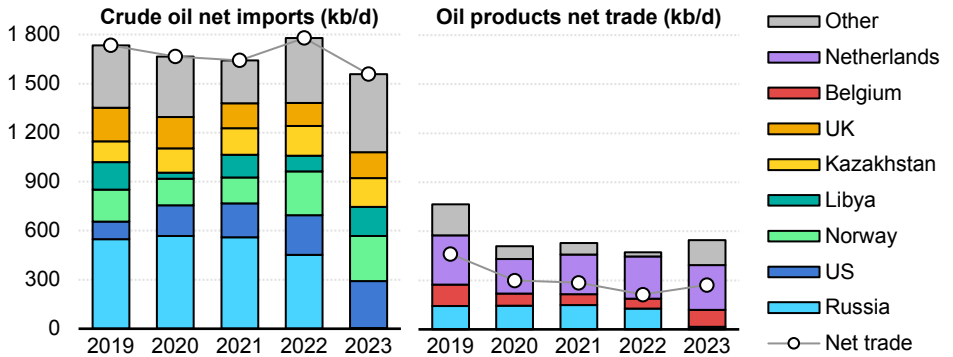
There are four transmission system operators (50Hertz, TenneT, TransnetBW and Amprion) in Germany with responsibilities for distinct control areas, though the entire country falls under a single wholesale bidding zone. It also has around 870 distribution system operators (DSOs) of varying size. Both wholesale and retail electricity markets in Germany are competitive. On the wholesale market, utilities can procure electricity under long-term contracts or on future or forward markets. Germany's future markets are among the most liquid in Europe. Short-term contracts are traded on various spot markets, the most liquid of which are the day-ahead and intraday markets. Utilities also compete in retail markets, and both household and industry end users are free to choose from different suppliers on either fixed or variable pricing structures.

Fuels

Oil

Having only limited domestic production, Germany imports its crude oil from a diversified pool of countries. Russian crude oil imports, which accounted for 34% and 25% of total national imports in 2021 and 2022, respectively (along with refined product imports), were almost entirely cut and replaced in 2023, mainly by increased imports from the United States, Norway and Libya.

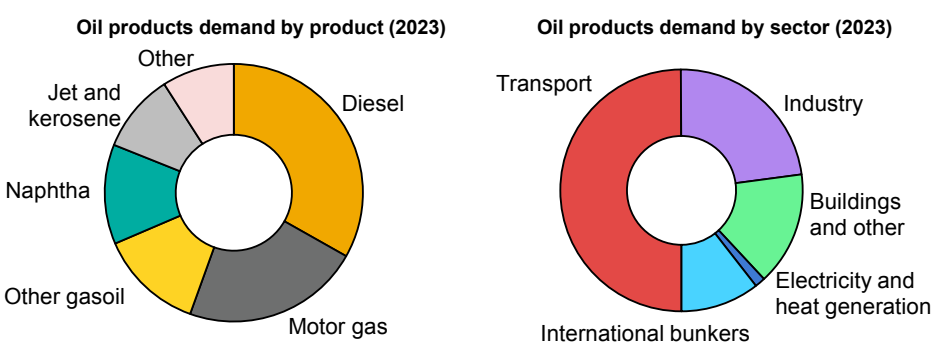
Crude oil and oil products net trade by country in Germany, 2019-2023



Source: IEA (2025), Oil Information.

Germany houses Europe's largest refining capacity, with 15 oil refineries. In this regard, its downstream oil industry plays an important role in security of supply, supplying end users and in job creation and regional economic development. The sector is also instrumental for supplying the petrochemicals industry. Based on a reduction in demand due to the economic situation, refining capacity is expected to drop from 101 Mt in 2023 to 90 Mt in 2025.

Oil products demand by product and sector in Germany, 2023



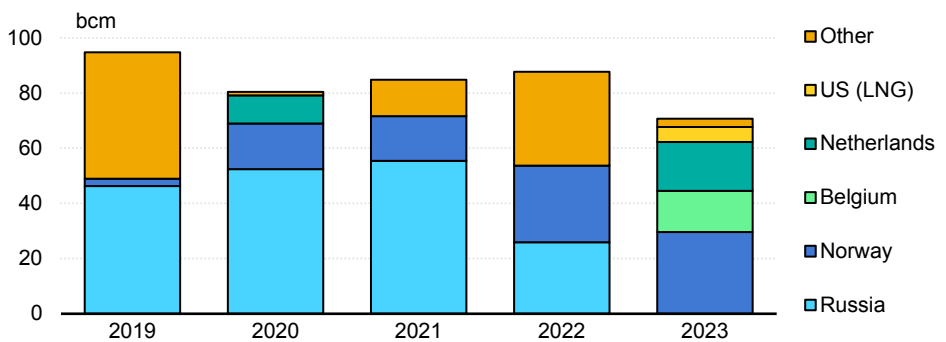
Source: IEA (2024), Oil Information.

Natural gas

Natural gas is a significant part of Germany's energy mix, accounting for 26% of final energy consumption in 2022, primarily used for electricity generation and heating in buildings. Domestic production of natural gas is limited, meeting only 6% of demand in 2023. It has been declining over the years, from 8.7 bcm in 2015 to 4.4 bcm in 2023, with a heavy reliance on imports to meet demand.

The natural gas price crisis following Russia's invasion of Ukraine caused domestic demand in Germany to drop by 18% from 2021 to 2023. In response, Norway emerged as Germany's primary supplier of natural gas, while liquefied natural gas (LNG) imports were quickly ramped up, accounting for 8% of total imports in 2023.

Natural gas imports by country in Germany, 2019-2023



Source: IEA (2025), Natural Gas Information.

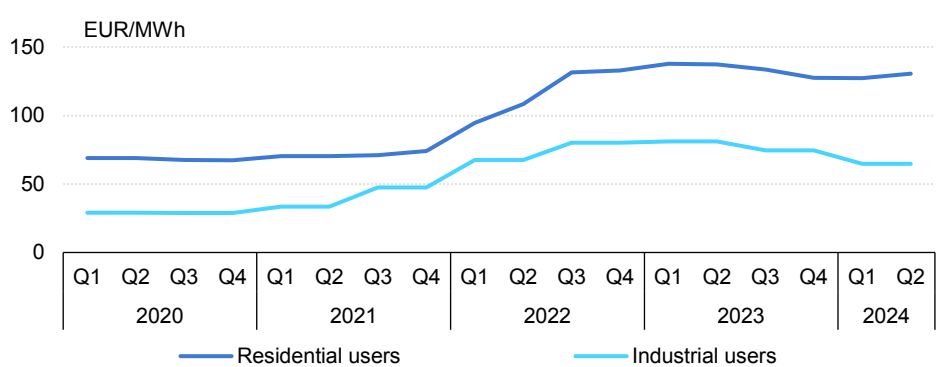
With an annual capacity of 5 bcm, the Floating Storage and Regasification Unit at Wilhelmshaven became the first German LNG terminal to start operations in December 2022, providing a rapid response to supply diversification. Other important LNG projects include the ENERGIE terminal in Mukran, which received its operating licence in mid-2024 and will supply up to 13.5 bcm of natural gas into the German pipeline network, and the Brunsbüttel land-based terminal, which is being developed to provide long-term LNG import capacity and aims to begin regular operations as early as 2027. The government expects land-based terminals to be converted to receive imports of hydrogen and its derivatives over time. The requirements for this conversion were legally formulated in the 2022 LNG Acceleration Act, which sets clear timelines (end of LNG imports by the end of 2043) and specific technical specifications for the conversion to hydrogen.

Germany's traditional natural gas infrastructure is a complex network of pipelines, storage facilities and distribution systems designed to deliver natural gas across the country. Key pipelines include Nord Stream 1, which transported Russian gas through the Baltic Sea; the Yamal-Europe Pipeline, now primarily used to transport natural gas from Germany to Poland; the Trans Europa Naturgas Pipeline, connecting the German and Dutch gas grids; and the Europipe I and II pipelines, which import natural gas from Norway's North Sea fields into Germany.

With around 40 gas storage facilities holding more than 24 bcm, Germany has the largest natural gas storage capacity in the European Union. The onset of Russia's war of aggression against Ukraine and the cessation of Russian gas deliveries via the Nord Stream 1 pipeline necessitated the rapid filling of these reservoirs to prevent a gas shortage. The storage facilities are particularly important for energy supply during the winter months, as they help meet peak demand in cold weather and thus contribute to energy security. Current law requires gas storage facilities to be 80% full by 1 October, 90% full by 1 November and 40% full by 1 February.

Natural gas prices in Germany doubled following Russia's invasion of Ukraine. The ongoing geopolitical crisis and resulting disruptions in Europe's natural gas market have strained both households and industries. While there has been a slight downward trend in prices over the past few months, competition in the gas market remains crucial for achieving further reductions as procurement conditions improve. Additionally, diversifying supply sources with LNG could help stabilise end-user prices, but Germany remains exposed to international market conditions for gas.

Natural gas prices by end user in Germany, 2020-2024



Source: IEA (2024), Energy Prices.

Coal

Although on a downward trend, the share of coal in Germany's total energy supply in 2023 remains high, at 18%. Over a quarter of electricity came from coal-fired generation, as the government targets to phase it out of the generation mix by 2038.

Germany is a lignite coal producer. In 2023, the volume of production was over 100 Mt, representing three-quarters of coal supply. The remainder is imported, in the form of hard coal. Russia was the largest importer until 2022, but imports fell by 96% in 2023. Instead, Germany now mostly imports coal from the United States, Australia and Colombia. Production has almost halved in the past ten years, reflecting a shift in the supply mix.

Recommendations

1. Ensure long-term policy and regulatory stability to support a secure and affordable clean energy transition as the key engine of German economic growth.

As energy prices have risen in recent years, the argument that energy transitions undermine affordability and competitiveness has gained traction in the German public debate. In reality, however, there is an increased urgency for an energy transition, not only to address the climate imperative. Notably, Russia's invasion of Ukraine and the ensuing energy crisis served as stark reminders of risks related to fossil fuel dependency. At the same time, the energy transition also provides an opportunity for German industry to gain competitive advantages in the clean energy industries of the future. Toward this end, amid the 2022/23 energy crisis, the German government correctly recognised that an acceleration of the energy transition offers the best longer term opportunity to regain competitiveness while bolstering energy security and keeping energy costs low. A number of strategies have been put in place to advance the energy transition, including plans to decarbonise the heating sector, expand renewable generation capacity, establish a national carbon pricing system and accelerate hydrogen development. The next stage of Germany's energy transition will be to support affordable electrification, underpinned by sectoral roadmaps that also clarify technological alternatives where electrification is not feasible. To realise the tremendous opportunities that the energy transition will bring Germany, continuity in

the policy and regulatory environment will be crucial to providing a stable, long-term investment environment. The government should continue to progress the future electricity market design proposals and ensure that there is a clear and stable investment framework for renewable electricity generation and supporting technologies as coal is phased out over the coming years. Likewise, long-term stability in funding and price signals will also be necessary to support certain technologies, including heat pumps, district heating and electric vehicles. Germany should also ensure sufficient, strong backing to energy-related research and innovation to maximise opportunities for industrial competitive advantages. Clear and transparent communication on the costs, benefits and time frames of the energy transition will also help ensure public support for the energy transition and the policies that support it.

2. Significantly ramp up efforts to decarbonise the transport sector.

Germany's transport sector is a clear sectoral laggard from an emissions reduction perspective. To reduce emissions in line with climate targets, the strong dominance of oil will need to be drastically cut by a range of policy measures. To start, Germany should significantly ramp up efforts to upgrade rail and public transport infrastructure to support modal shifts away from the heavy reliance on road transport, which accounts for nearly 95% of domestic transport emissions. This should be supported by long-term and stable funding packages.

In the road transport segment, EVs are expected to play the largest role in decarbonisation. The government concludes that to meet the sector's climate target, basically all new cars should be electric by 2030. However, Germany removed its previous purchase incentives for EVs at the end of 2023, following the court ruling on KTF funding, and EV sales have recently slowed down. The government should provide alternative long-term budget-neutral measures to accelerate EV uptake, for example, a bonus-malus tax structure for vehicle purchases that incentivise sales of low-emissions alternatives over fossil fuel vehicles. New measures should target not only privately purchased cars, but also leasing and company cars, which account for the majority of cars in the German market. EV sales should be complemented by faster deployment of charging infrastructure, building off the Charging Infrastructure Master Plan (and ensure sufficient planning co-ordination with the electricity system). Germany should also explore options to increase the role of sustainable biofuels in transport. While its GHG quota policy is an effective way to increase the share of

renewables in transport fuels, the government should ensure even treatment of compliance options. More specifically, it should increase transparency around the rationale for multipliers or consider alternative options such as linking support to consistent, third-party certified GHG life cycle assessments of different types of renewable fuels. More broadly, the transport sector would also benefit from closer co-ordination across ministries with jurisdiction in this area, complemented by stable financial support.

3. Clarify the role natural gas is expected to play through the energy transition.

Natural gas still retains a large role in Germany's energy system, accounting for roughly a third of final energy consumption, with large shares in the electricity, industry and buildings sectors. However, Russia's invasion of Ukraine and the ensuing energy crisis in Europe highlighted the considerable risks that stem from natural gas import dependency. Even with more import diversification through LNG, Germany still remains exposed to high natural gas prices amid periods of tight global supply. In line with emissions targets, the government's gas diversification strategy was based on the ability to convert LNG import terminals to receive hydrogen down the road.

Germany could benefit from a broader strategy on the role of natural gas in the energy transition, including time frames and expected prices, to underpin its policies supporting the development of renewable energy. Such a strategy should also address the financial impacts of decommissioning natural gas infrastructure that cannot efficiently be repurposed, to avoid such impacts from creating the wrong incentives for future-proof investments.

On the demand side, while Germany has recently developed a clear roadmap to wind down natural gas dependency in its buildings sector through heat pumps and district heating, the industry and power sectors still face uncertainty on the role of natural gas through the energy transition. The industry sector, in particular, is facing growing threats to competitiveness, in part stemming from high natural gas costs. A more concerted effort to promote energy efficiency and electrification (see the recommendation on lowering electricity prices) in the short term, along with increasing the penetration of hydrogen and CCUS in the longer term, represent viable pathways, but at present, the continued dependency on natural gas remains without a clear end in sight (though the EU ETS will erode its role over time). Additional clarification on the natural gas exit ramp for the industry sector, including time frames, would provide

industry with the certainty needed to make future-proof investments, including in required import infrastructure (for both natural gas and hydrogen) and industrial clusters.

In the power sector, unlike coal, Germany does not have a discrete policy or roadmap to exit from natural gas generation, though the target of 100% fossil-free generation by 2035 suggests that the exit will need to take place over the coming decade. The EU ETS will be the primary driver for declining natural gas generation. At the same time, these plant closures (alongside rising demand) are raising concerns about generation adequacy. The government's previously planned Power Plant Strategy attempted to address this issue by tendering 12.5 GW of new natural gas-fired power plant capacity that could later run on hydrogen. In this way, the construction of new hydrogen-ready gas-fired capacity could avoid a fossil fuel lock-in that is not at odds with the electricity generation target, as long as the fuel switch takes place on time. This indicates that hydrogen will play a role in Germany's future power system but clarification is needed to what extent, given other competing uses in the next ten years, raising some questions around the viability of hydrogen-ready gas plants. Moreover, a broader look at adequacy is needed to include other flexibility options such as industrial demand response, storage and interconnections (see recommendations on electricity), which may displace the need for additional generation capacity. While gas plants might very well continue to play a role in grid balancing beyond the 2035 time frame, investors need more long-term clarity on the future role of natural gas in the electricity mix. With this in mind, the government should move ahead with the future electricity market design proposals, including a capacity mechanism, and explain how these planned capacity auctions might impact the need for additional dispatchable generation capacity (see the electricity section for more details).

Focus areas

1. Electricity system optimisation

Germany is making impressive strides in its energy transition, rooted in its *Energiewende* strategy from 2010 that laid the groundwork for an energy system transformation early on. Nowhere is this progress more evident than in the electricity sector, where Germany has witnessed a rapid shift away from fossil fuels and nuclear toward renewable energy. Recent measures to accelerate the country's permitting system for renewables as well as the attractive incentives for investments in renewable installations have been a lynchpin of the successful shift, and Germany continues to benefit from strong growth in both wind and solar power.

Nonetheless, the energy transition has not come without its costs. A number of nuclear closures have been concentrated in the energy-hungry southern states, while most wind power is located in the resource-rich northern regions, creating a regional supply-demand imbalance that has led to pronounced grid congestion and hefty associated costs. The costs have contributed to high consumer prices for electricity that serve as a disincentive for electrification and could erode public support for the energy transition.

Therefore, Germany is at an important crossroads in its energy transition. To fully realise a successful transition, including a move toward electrification of end uses such as transport and heating, the German electricity system will need to further evolve. Not only will the government need to ensure an enabling environment for additional growth in renewables generation capacity, but likewise to ensure sufficient investments and policy/regulatory settings to support much-needed grid investments and flexibility resources. Together, generation, grids and flexibility will all play vital roles in achieving a more efficient, secure and affordable electricity system.

Load growth

According to the System Development Strategy, gross electricity demand in Germany is expected to grow to more than 950 TWh in 2035 and up to 1 100-1 300 TWh in 2045 (relative to 525 TWh in 2023). Industry demand is expected to grow from 214 TWh to 250-320 TWh in 2035 and 300-400 TWh in 2045. These numbers are based on comprehensive long-term scenarios covering the electricity, gas and hydrogen systems.

Generation

Germany's electricity mix has already experienced transformative changes in recent years, driven by the overarching Energiewende strategy. In particular, the country's nuclear capacity completely closed in 2023, and coal-fired generation capacity experienced a marked reduction. At the same time, the country has seen a major surge in renewables capacity, notably wind and solar PV. New renewables capacity will be the main driver to underpin the country's target to source 80% of electricity from renewable sources by 2030 and 100% by 2035. The government estimates that the target will translate into a requirement for 600 TWh of domestic renewable electricity by 2030 (relative to 2022 volumes of around 245 TWh), from the following sources: onshore and offshore wind, solar PV, imported electricity, and power plants using green hydrogen. At the same time, clarity on the pathway to exit from fossil fuels is also needed.

Coal

While coal remains a significant part of the German electricity mix, its capacity has fallen by 34% since 2012. Its share of the 2023 generation mix stood at 27%, compared to 46% in 2012. The decline to date has mainly been driven by market conditions and EU ETS prices. The German government's goal is to phase out coal-fired generation by 2038 at the latest, though it expects EU ETS prices to push an exit sooner.

Following up on recommendations from a society-wide consultation process, in 2012, the German government formally enshrined a coal phase-out into law. The law provides a detailed roadmap for the phase-out, with separate plans for lignite and hard coal along with compensation to coal plant owners for closures and up to EUR 41 billion in support for coal-dependent communities. The exit from lignite will have more significant economic impacts given the outsized role that lignite mining

plays in certain regions, whereas Germany closed its last hard coal mine in 2018. Relative to 15 GW each of lignite and hard coal capacity in 2022, the plan calls for 8 GW of remaining hard coal and 9 GW of lignite by 2030, both winding down to zero by 2038 at the latest. The government reached a separate agreement with the industrial and coal-producing region of North Rhine-Westphalia and coal plant operator RWE to phase out lignite-fired generation by 2030. The plan calls for regular reviews every three years to determine whether the final exit date can be brought forward to 2035.

Natural gas

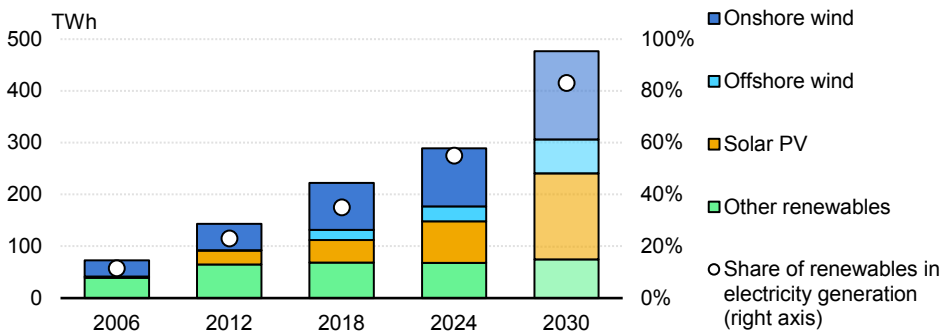
In contrast to coal, natural gas has maintained its share in Germany's generation mix, averaging around 15% over the past decade. Notably, as variable renewables have assumed a dominant role in the fuel mix, natural gas has played an increasingly critical role in balancing the grid. In fact, Germany saw growth in natural gas generation capacity of 11 GW over the period 2010-23. Natural gas is also the predominant fuel (accounting for around half) in co-generation plants. Moreover, the permanent closure of the final nuclear plant and forthcoming coal closures are expected to increase reliance on natural gas for electricity generation in the short term. The government committed to introduce a capacity mechanism to support investments in dispatchable capacity.

Renewables

The growth of renewables in Germany's electricity system is a clear success story for the country. Impressively, for the first time, Germany saw renewables produce more than half of power generation in 2023.

Early growth in the sector was driven by the Renewable Energy Sources Act (EEG), which in 2000 established 20-year feed-in tariffs along with guaranteed grid connectivity and preferential dispatch. An EEG surcharge on electricity consumers financed the subsidies. As costs escalated, the support programme shifted in 2017 to one based on competitive auctions. Today, the auction system continues to produce strong results for renewables capacity growth, as cost reductions and favourable terms will support the sector's expansion in the coming years too.

Renewable electricity generation (2006-2024) and forecast (2030) in Germany



Note: Other renewables includes hydro, bioenergy and geothermal.
Sources: IEA (2024), World Energy Balances and IEA (2024), Renewable Energy Progress Tracker.

Wind

Onshore wind has to date experienced the strongest growth based on favourable economics, though future expansions will be constrained by available funding under the EEG as well as limited locations for new installations. In this context, the repowering of older, smaller facilities to upgraded wind parks with larger capacities is expected to be a notable source of growth. Nonetheless, the sector continues to see strong growth, with the Federal Network Agency (BNetzA) auctioning 12 GW of capacity in 2024, and the November auction receiving a record number of bids (1.5 times oversubscribed). The improved auction outcomes in 2024 relative to 2023 were partly attributable to permitting reforms the government undertook to implement EU emergency regulations on permitting that call for a provision to override public interest opposition to accelerate wind projects. Overall, the government targets an expansion of onshore wind capacity to 115 GW by 2030 and up to 160 GW by 2040 (relative to 61 GW in 2023).

Beyond onshore wind, offshore wind represents an important growth opportunity that may require additional policy or regulatory support to be realised. The government has targets to realise 30 GW of offshore wind capacity by 2030, 40 GW by 2035 and 70 GW by 2045 (relative to 8.9 GW as of June 2024), based on competitive auctions outlined under the Offshore Wind Energy Act. Amendments to the Act further support

the sector through accelerated planning and approval processes as well as improvements in tender design. Successful bidders also secure grid connections as part of the auction process. The government planned to auction 8 GW of capacity in 2024. While the government is helping to finance an expansion of the Port of Cuxhaven, which supports the import of wind components, more systematic upgrades to ports along with broader supply chain infrastructure is likely required to bolster the sector's ambitions. Grid connection delays for offshore wind projects also remain an impediment and could slow capacity additions.

Solar

Solar PV is also a central pillar of Germany's goal of meeting 80% of electricity production from renewable sources by 2030. Revisions to the EEG in 2022 included a target to achieve a total capacity of 215 GW by 2030 (from around 83 GW in 2023). The country has experienced a renewed surge in solar PV investments in recent years, notably rooftop solar. As a result, despite being far from a sunny country, Germany has positioned itself as a leading country for solar power. The country's solar growth has been driven both by auctions for installations larger than 1 000 kW of capacity and by support schemes such as feed-in tariffs for smaller, decentralised systems.

In response to weaker market conditions for solar investments in 2022, the government introduced reforms in 2022 and 2023, including streamlining permitting and lifting auction ceiling prices (by 25%) to reflect higher capital costs, which resulted in renewed momentum for solar auctions. As a result, the December 2023 auction for ground-mounted solar projects was oversubscribed more than three times its 1.6 GW of capacity.

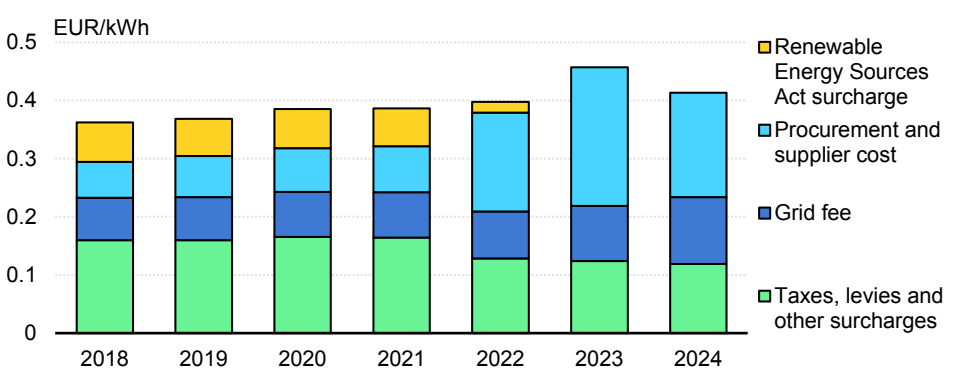
The 2022 revisions to the EEG also included higher feed-in tariffs for rooftop solar installations, which have led to a pronounced boom in investments. The government also simplified grid connection requirements for residential systems, further supporting their growth. More recently, in 2024, the government passed Solar Package 1, based on the BMWK's 2023 Solar Strategy, which included higher feed-in tariffs for commercial and industrial projects. It also simplified rules and improved incentives for balcony solar installations (including to facilitate installations by tenants) as well as community solar projects. Importantly, the favourable conditions for rooftop solar have been matched by swelling popularity for solar technology, especially following the energy crisis in 2022.

Affordability and competitiveness

Ensuring the affordability of electricity through the energy transition will be a paramount objective for Germany. Not only will keeping prices low for households be imperative to ensure fairness and equity during the transition, but it will also inform support for the transition itself.

In response to the energy crisis due to Russia's invasion of Ukraine, the German government in 2022 took the decision to do away with the surcharges on electricity supply to households to finance support for renewables. The EEG surcharge (which made up around a fifth of consumer prices) had led German consumers to pay among the highest electricity prices in Europe. Instead, renewables support measures are now being covered by the general state budget. The removal of the surcharge will not only provide relief to German households (estimated savings are roughly EUR 200 per household annually) but also help bring down the relative cost of electricity vis-à-vis fossil fuels to promote greater electrification, especially in heating and transport.

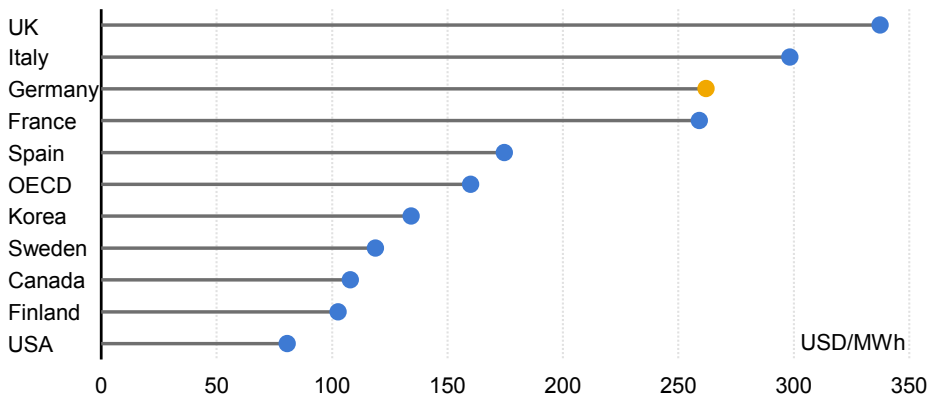
Electricity price components for households consuming 3 500 kWh per year in Germany, 2018-2024



Source: IEA analysis based on German Association of Energy and Water Industries, BDEW electricity price analysis March 2025 (Accessed: 31 March 2025).

Moreover, the German economy is built on a large export-orientated industry sector, many of which are global leaders in their fields and major job creators in the country. Energy prices – and especially electricity prices (as more electrification and low-carbon hydrogen become mainstays of the future energy system) – will be a key determinant of the future competitiveness of German industry. Already, pursuant to the 2022 energy crisis and consequent gas and electricity price increases, the country is facing a decline in industrial activity, and several firms have indicated they are considering cutting output or relocating facilities abroad.

Average electricity price for industry users in selected countries, 2023



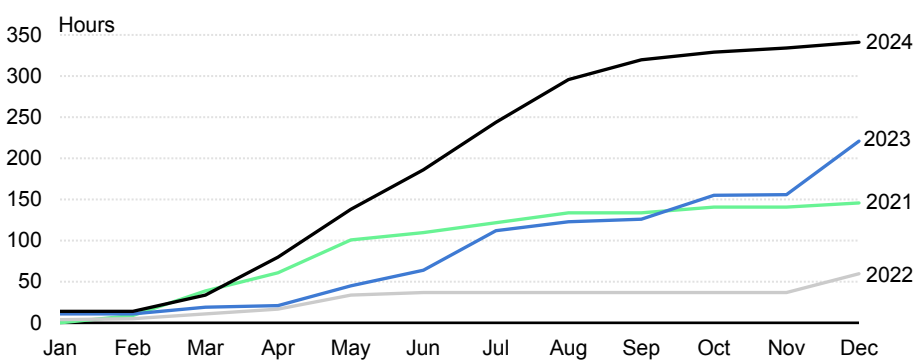
Source: IEA (2024), Energy Prices.

In 2024 the government brokered a deal with power suppliers to cap prices for certain large businesses, but such types of temporary support measures are not sustainable over time. Moreover, a constitutional court ruling on debt limits will further hamper the government's ability to offer public support to mitigate price impacts. In fact, a 2023 government proposal to subsidise electricity prices was eventually scrapped following opposition from the Ministry of Finance and the court ruling. Rather, Germany will need to address economic inefficiencies in its electricity system and optimise its utilisation to bring down overall costs while ensuring security of supply. A clear plan for bringing down system costs will not only support needed investments across the electricity system, it will also provide clarity to German industry and support a continued, strong industrial sector.

Electricity prices

Reduced supply of Russian gas following Russia's invasion of Ukraine led to unprecedented electricity prices in 2022. Wholesale electricity prices in Germany peaked in August 2022 at 699 EUR/MWh, more than five times the price in August 2021. In response to the crisis, Germany accelerated the deployment of renewable energy projects as part of a broader strategy to reduce reliance on imported fossil fuels, supported by the European Commission's REPowerEU plan. Since the peak in electricity prices in the third quarter of 2022, the share of solar and wind generation has increased by 45%. These measures, along with the diversification of gas supply (and a softening of gas prices), have contributed to the reduction in wholesale prices since 2022. The surge in renewables generation has also led to an increase in price variability. The number of periods of negative electricity prices during periods of high output has increased, exacerbated by the inflexibility of traditional power plants, especially nuclear and coal-fired plants, to be easily turned off or ramped down. Negative electricity prices signal the need for more flexibility in the system and encourage shifts in consumption patterns. They can also serve as a deterrent to new investment in power generation if investors perceive a risk of insufficient returns.

Cumulative hours of negative electricity prices by month in Germany, 2021-2024

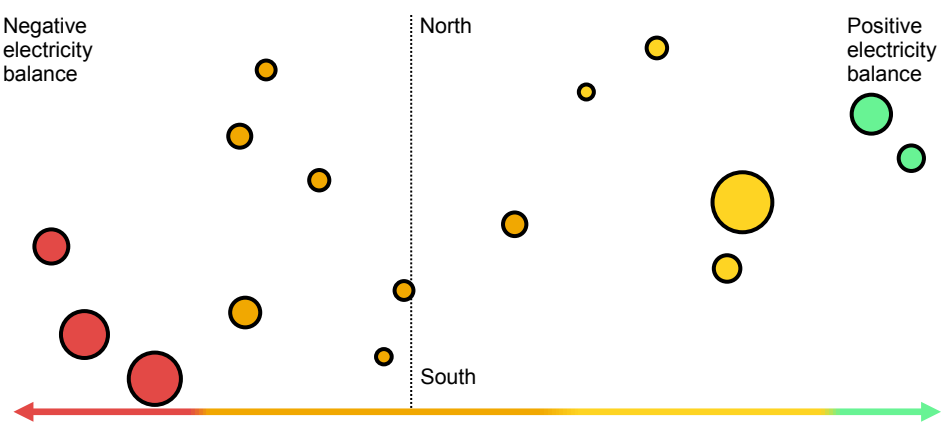


Source: IEA analysis based on ENTSOE (2024), Transparency platform, collected through the Real-Time Electricity Tracker.

Regional imbalances and grid congestion

The regional imbalance between higher shares of wind capacity located in northern Germany and major demand centres located in the south and west of Germany persist. The imbalance has been exacerbated by the closure of power plant capacities (nuclear, coal and gas), concentrated in the high-demand southern and western regions, the continuous increase of wind capacities in the north, and increasing cross-zonal trade requirements. The result is a continued geographical mismatch between generation capacity and demand, which the transmission grid struggles to keep up with, even in the face of expansions and debottlenecking efforts in recent years. The ensuing grid congestion and transfer losses prevent the system from maximising its efficiency and lead to curtailment in the north and redispatch measures in the south. The losses can cost end users sizeable sums and insufficient grid capacity also creates loop-flow challenges for Germany's neighbours. The loop-flow challenges have been mitigated by investments in phase-shifting transformers and by higher trade requirements.

Estimated electricity balance by federal state in Germany, 2022

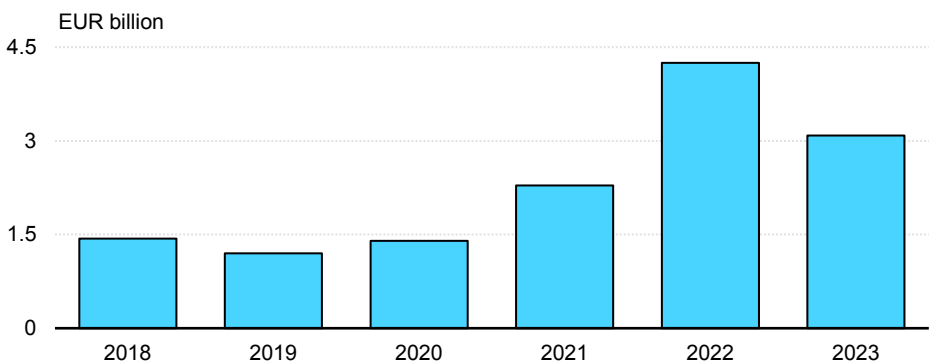


Note: Bubble size indicates the annual electricity consumption per federal state.
Source: IEA analysis based on data from the statistical offices of the German federal states and LAK Energiebilanzen.

Grid congestion in Germany has rapidly increased in recent years, with associated costs more than tripling between 2019 and 2022. The issue has become a major

problem for the system, driven by three interrelated factors: 1) insufficient transmission capacity to transport the high volumes of renewable generation from the north to consumption centres in the south; 2) the closure of power plants in the south; and 3) the policy decision to maintain a single price zone while increasing cross-zonal trade. The costs for congestion measures such as redispatch, countertrading and the use of grid reserves peaked at EUR 4.25 billion in 2022, especially due to rising fuel prices in the wake of the energy crisis in Europe. These measures result in additional costs for consumers, who bear the financial burden through increased grid charges. Preliminary estimates suggest a decline of redispatch costs in 2024 well below 2021 levels.

Costs of grid congestion management measures in Germany, 2018-2023

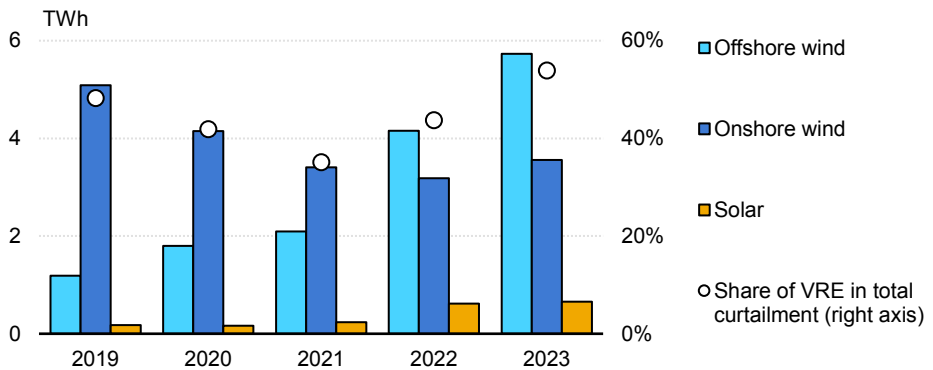


Source: IEA analysis based on Federal Network Agency (2024), Grid congestion management (Accessed: 24 October 2024).

Curtailment of renewable electricity has become a key measure adopted to address grid congestion. Curtailed renewable energy increased to 10 TWh, accounting for 53% of total electricity curtailed in 2023. While smaller scale grid expansions have helped reduce onshore wind curtailment, major grid investment decisions to strengthen the north-south corridor are still pending. This delay increased curtailments of offshore wind farms, as most wind capacity is in the north while major industries and load centres are in the south. This geographical mismatch between renewable generation and consumption results in higher curtailment, especially when limited interconnection capacity prevents exporting renewable electricity. In

November 2023, the government introduced a “use instead of curtail” regulation that incentivises additional electricity demand by offering excess generation to specific consumers in certain regions facing high curtailment probabilities. Nonetheless, curtailment challenges persist.

Renewables curtailments for grid congestion management in Germany, 2019-2023



Note: VRE = Variable renewable energy.
Source: IEA analysis based on Federal Network Agency (2024), Grid congestion management. (Accessed: 24 October 2024).

To support more efficient operation of the electricity system, BMWK released proposals in August 2024 for an electricity market design of the future, based on the findings of the 2023 Platform Climate-Neutral Electricity System. The options laid out in the report are based on four fields of action: 1) the renewables investment framework; 2) the investment framework for dispatchable capacity; 3) locational signals; and 4) demand flexibility.

Transmission grid

Insufficient power grid capacity remains a notable impediment to Germany’s energy transition. A key solution to alleviating its regional power imbalances and addressing grid congestion is to increase transmission grid capacity, especially from the north to the south. The government recognises the impediment and has been taking measures to remedy it, though delays remain a bottleneck to projects.

Germany's transmission system operators (TSOs) have planned major expansions of power transmission lines under successive network development plans to transport abundant wind energy in the north to power consumption centres in the south. Originally due to be completed before the last nuclear plants shut down at the end of 2022, permitting and construction delays have meant that projects are running years behind schedule. For example, the Ultranet line to connect offshore wind in the North Sea to industrial demand centres in the south is estimated to require around 13 500 permits. The first sections of the A-Nord, Ultranet, SuedLink and SuedOstLink projects have now all completed their permitting process and are under construction. The remaining sections will follow successively through the end of 2025.

In 2023, BNetzA announced a plan to significantly expedite the issuance of permits for grid infrastructure, so that by the end of 2024 it would have approved a total of 2 800 kilometres (km) of lines and a total of 4 000 km by the end of 2025, a sizeable jump from previous years. To date, progress has been limited to individual sections of a line rather than across larger areas. In total, around 16 000 km of new high-voltage lines or reinforcements are expected to be built across Germany in the coming years, according to the regulator, based on national law. Germany improved, among other things, a mechanism that allows for early construction of sections of a line before the final planning approval decision for an entire project is handed down. For instance, the early construction approval for the A-Nord pipeline allowed for construction of the Lower Saxony 2 segment of the line to begin seven months earlier than planned.

As in other countries, there has been strong local opposition to power lines in Germany, in some cases manifesting as citizens' protests mobilising large segments of local populations. To minimise the risk of local opposition, most high-voltage direct current lines are planned for underground construction, despite significantly higher costs compared to overhead lines. For example, planning discussions for the Suedlink transmission project to send wind power from the north to the south of Germany began in 2014. Originally conceived as an overhead line project, it was forced to shift to underground cables in the face of strong local opposition. The change is estimated to have tripled the pipeline's costs and led to a three-year delay. The project is now planned for completion in 2028, though additional delays are possible.

Bidding zones

Unlike some other European countries with regional supply and demand disparities, such as Norway and Sweden, Germany is not divided into bidding zones. Rather, the entire country falls under a single bidding zone, together with Luxemburg, which keeps wholesale prices uniform throughout the country. This situation, compared to a situation with several bidding zones, benefits consumers in Germany's southern and western industrial heartlands, where most demand is concentrated, while most wind energy is generated in the north.

In August 2022, ACER decided to undertake a Bidding Zone Review in France, Germany, Italy, the Netherlands and Sweden to assess the current status quo relative to alternative bidding zone configurations. For Germany, in light of the considerable congestion on its transmission grids, ACER determined that four different configurations are to be assessed: two different configurations to split into two bidding zones, one configuration with three bidding zones and one configuration with four bidding zones. ENTSO-E is undertaking the review. EU regulation states that bidding zones should be structured based on systematic congestions in the transmission grid, while the review will determine whether alternative configurations increase operational efficiency and cross-zonal trade opportunities. The TSO review is due to be completed in spring 2025, with a government decision on the recommendations due six months later. Implementation of bidding zone configuration changes, if any, is subsequently expected in 2027, at the earliest.

The debate over splitting Germany's bidding zone is not new as regional imbalances have led to redispatch and curtailment measures for some time (and were also salient in the IEA's previous *Energy Policy Review* in 2019). However, political opposition to splitting Germany into more than one bidding zone remains strong. While northern states favour a split to take advantage of abundant wind resources that would likely result in lower power costs (and have been frustrated by the slow pace of grid expansions to alleviate the issue), southern and western states (Baden-Württemberg, Bavaria, Hesse, North Rhine-Westphalia, Rhineland-Palatinate and Saarland) are strongly against a split, mainly due to the higher prices that might result. Moreover, power plant closures in southern regions in recent years could exacerbate the potential price increase that a bidding zone split would create in the south.

Germany might need to reconsider the economic efficiency of applying only a single bidding zone across the entire country. The ongoing investigation by TSOs and the final recommendations will be based on detailed technical assessments. Therefore,

the government should not take a political decision to preclude any bidding zone splits, instead heeding the advice of the review and maintaining an open mind about the possibility of implementing differential pricing across Germany to address the inefficiencies and hefty costs that come with grid congestion. Germany could look to Italy's bidding zone structure, where power producers face differentiated prices based on generation capacity and demand (thereby still providing price signals to generation investments), while consumer prices are levelled under a single national price.

System flexibility

Germany can also look to ramp up efforts to support flexibility measures to improve the operational efficiency of its electricity system, including incorporating storage, distributed resources, demand-side management (DSM) and digital upgrades.

Equally important, as EVs and heat pumps become bigger parts of the energy transition, Germany will need to undertake major upgrades to distribution networks and align transmission and distribution network planning.

Storage

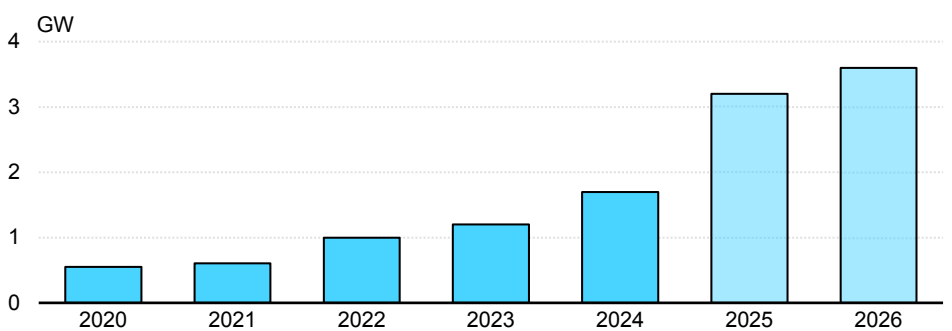
As Germany's power system shifts toward greater dependence on variable renewable generation, especially in a world of 80% renewables by 2030, the country will need to complement generation growth with flexibility resources. In this regard, storage will increasingly become a cornerstone of the German electricity system, from both pumped storage and batteries. Pumped storage has played a role in Germany's power system for a long while, though its future expansion potential is limited owing to constraints on suitable locations. Heat storage within heat networks that are used in combination with large-scale heat pumps can also improve flexibility in the electricity system. In the future, hydrogen storage can also play an important role in electricity system balancing. BMWK released an electricity storage strategy in 2023 to lay out a framework for development of the storage market in Germany on the pathway to a carbon-free electricity sector by 2035.

Germany recently demonstrated progress on expanding the role of storage in its energy system, led by household storage systems. Consumer trends that favour decentralised power generation, heat pumps and EVs are the main drivers. High electricity prices are also an important factor. In fact, 80% of rooftop solar installations in Germany in 2023 were accompanied by storage. As a result, Germany saw a 46% increase in energy storage in 2023 relative to the previous year, according to the

storage industry organisation BVES. Around 1.8 million single-family homes had energy storage systems in place by the end of 2024, or around 15% of the market segment. Nonetheless, Germany will need to see still higher volumes of storage deployed to ensure security of supply through its electricity transition, especially utility-scale storage.

Utility-scale batteries are already an important provider of ancillary services in Germany's electricity market, notably frequency response and reserves, supported by reforms that allow battery storage assets to access the markets for these services. Batteries also played an important role in alleviating grid congestion in Germany as grid boosters. Under the 2019 grid booster initiative, the regulator approved 950 MW of storage assets as part of the TSOs' 2030 network development plan, and a total of 450 MW are already under construction in the control areas of two TSOs. Beyond frequency control services and grid boosting, another driver for utility-scale storage in Germany is the Innovation Tender for co-located generation and storage assets and optimising energy consumption at industrial sites. The elimination of double charging of taxes and grid tariffs for storage has also lent important support to the market. Large-scale battery capacity in Germany at the end of 2023 was 1.5 GW, with several new projects also under construction.

Large-scale battery storage capacity (2020-2024) and planned capacity (2025-2026) in Germany



Note: The planned capacity is the capacity already registered in the German market database.
Source: IEA analysis based on RWTH Aachen University (2025), Battery charts (Accessed 28 January 2025).

Flexible demand

In addition to storage, flexible demand has an important role to play in balancing Germany's renewables-dominated electricity system, today and especially in the future. To support consumer participation in the electricity market more actively, a combination of incentives, enabling infrastructure and price signals all contribute.

DSM is still in its early days in Germany. It involves managing demand to boost the flexibility of the system by treating demand as a service for grid balancing. The German energy agency Dena notes that the industry sector, which consumes 44% of the country's electricity, offers DSM potential of around 5-15 GW. However, in Germany, the Electricity Grid Charges Ordinance imposes a constraint on flexible demand by offering grid fee reductions to baseload energy-intensive demand, impeding DSM opportunities. Dena – in collaboration with state governments in Bavaria and Baden-Württemberg, which have outsized exposure to the nuclear phase-out – is carrying out pilot programmes on DSM for industry to support broader application of DSM.

Given the impressive growth that Germany is experiencing in rooftop solar PV (plus storage) deployment (along with EVs and heat pumps), so-called prosumers represent an important resource that can help the country improve the flexibility of its electricity system. However, Germany does not appear to be maximising this potential. Notably, regulatory and bureaucratic hurdles appear to be constraints, as does lack of information. In particular, the high regulatory burdens placed on prosumers as designated "energy suppliers" serves as an impediment. The individual use of aggregation services to allow consumers (and prosumers) to collectively provide services is also limited.

Germany is also pursuing pilot projects to use demand-side flexibility from heat pumps to bolster grid security. The German manufacturer Viessman, along with TSOs 50Hertz and TenneT, launched a pilot project to aggregate heat pump flexibility across participating Viessman customers and offer the savings to the TSOs to manage grids during peak loads. The pilot's target is to incorporate 100 heat pumps. Nonetheless, several barriers remain to widespread application, including complex certification standards and insufficient remuneration for residential demand-side flexibility in system balancing and ancillary services markets.

Germany has a very high share of consumers with flat electricity tariffs, so a shift toward time-of-use or dynamic tariffs would not only support flexibility but could also result in direct cost savings for consumers, beyond system-level benefits.

Smart meters are a key enabler for encouraging flexibility in demand. Toward this end, Germany has struggled with its smart meter rollout for years due to legal and bureaucratic challenges, lagging behind many other European countries in this regard. Digital security and privacy protection concerns, in particular, are salient in Germany. With its decentralised energy transition, Germany is aiming to replace large-scale generation plants with millions of renewable energy systems. This is only possible if generation and consumption can be digitally controlled and networked while ensuring IT security and data protection. The European Commission recently made it clear through the Cyber Resilience Act that, in view of system risks, smart meters must meet the highest cybersecurity requirements (classification in the “critical category” in Annex IV). Initially, Germany had imposed a three-manufacturer rule that required certification by at least three independent manufacturers of smart meters to ensure competition in the smart meter market. Afterwards, a lawsuit by several companies against a previous decision of the Federal Office for Information Security to allow the start of the rollout led to a significant delay. Consumer protection groups also voiced opposition to the rollout based on concerns over higher electricity prices.

To speed up digitalisation efforts, the parliament adopted a federal law in 2023 that renews actions on digitalisation and a smart meter rollout. Importantly, the law would enshrine the smart meter rollout timetable into law by 2030 and do away with the three-manufacturer certification given the maturity of the smart meter market as well as the prerequisite of an administrative decision to start the rollout. The law would instead allow for immediate rollout of certified meters, with more sophisticated applications allowed under subsequent updates. Costs will also be distributed in a way that sees network operators bearing the brunt, keeping consumer fees low. It also requires all electricity suppliers to offer dynamic pricing by 2025 (currently required only for those supplying at least 100 000 customers). As of Q3 2024, more than 1 million smart meters were in use in Germany, which is around four times the level at the end of 2022.

Another important piece to encourage behind-the-meter flexibility is improving the integration of consumer systems onto the distribution grid. In the German context, ensuring that distribution grids are fit-for-purpose through the energy transition will be at least as important as expanding transmission grids. To this end, not only will the government need to address regulatory impediments for consumers, but it will also

need to facilitate upgrades by (numerous and varied) DSOs. Importantly, decentralised flexibility on distribution grids can also go a long way to addressing congestion on transmission grids. For their part, DSOs started compiling regional scenarios for the energy transition in 2023 across six planning regions to increase co-ordination among network operators. The scenarios, which are updated every two years, form the basis for distribution network development plans. Network operators estimated that EUR 110 billion would be required over the decade 2023-33, which will be passed on to consumers through grid fees. The government has recently implemented an EU directive on flexible connection agreements to integrate more renewable energy into distribution grids in areas with limited grid capacity.

Recommendations

4. Prioritise actions to lower electricity retail prices.

German consumers face among the highest electricity prices in Europe. Already, the government has taken a significant and welcome step toward alleviating prices by removing the EEG surcharge. Energy-intensive industrial consumers also receive various forms of relief and compensation for electricity prices. Nonetheless, high prices persist across all consumer segments. Not only do high electricity prices impact affordability and competitiveness, but they also serve as a major obstacle for the electrification needed to realise energy transition goals. To start, the government could consider lowering taxes on final electricity prices to support affordability, competitiveness and electrification outcomes.

Moreover, compared to other countries, Germany faces relatively high grid fees. This is partly due to legacy costs of past grid expansion investments to accommodate the shifts in power generation that the country has experienced. On top of this, regional imbalances and still insufficient grid capacity create large inefficiencies and hefty congestion management costs that are also reflected in grid fees. Moreover, as Germany looks to a massive new expansion of both the transmission (including to accommodate offshore wind) and distribution grids, over EUR 400 billion in new costs will have to be socialised through grid charges. Therefore, a priority for the German government should be to explore all possible options to quickly soften the impact of grid charges on consumers, working with the regulator (which oversees grid fees). For example, the government could consider absorbing some of the charges into the state budget, which would help alleviate near-term challenges. Innovative frameworks such as the amortisation account used to finance the Hydrogen Core Network could

be explored to finance new electricity lines too (both public and private financing). To avoid further increases in grid costs, the IEA also encourages the government to look at ways to use the existing grid as efficiently as possible.

5. Create clearer locational signals to improve system operation and reduce the need for new grids.

Building new grid lines takes lots of time and money. To manage the energy transition with rapid growth in variable renewable generation, distributed renewable resources and significant electrification of end-use sectors, the existing grid infrastructure needs to be used as efficiently as possible. This requires a more concerted effort to ensure that electricity assets are sited where they best serve grid needs and align with future grid development plans. One method for doing this is to ensure that new grid connections are located in places that support efficient grid operation now and in the future. The government should explore the possibility of including locational signals for new renewable power generation in forthcoming renewables auctions, while being careful to avoid barriers to the deployment of new renewable energy sources. Batteries and electrolysers will also increase significantly in the coming years and can play an important role in balancing the electricity system and improving grid use. Germany subsidises these technologies by exempting them from grid connection fees. For new connections, the support should be tied to locational needs, so that new connections only receive grid fee concessions in locations that the system operator deems suitable to optimise grid operation.

The industry sector can play a role in locational flexibility. Currently, a sizeable disincentive for flexible industrial demand (beyond structural ones) is the Grid Charges Ordinance that offers grid discounts to large consumers for steady, baseload demand. While removing the concession could further erode the competitiveness of an already ailing sector, the government should still explore options to offer incentives to these consumers to manage demand in ways that support grid-balancing needs.

Finally, locational signals can also be provided by bidding zones in the electricity market. Having multiple bidding zones can attract new investments in areas suitable for the electricity system and provide benefits to efficient electricity market operation such as reduced redispatch and curtailment costs. Such a split could also present attractive opportunities to site new green industrial facilities in more parts of Germany, a prospect that is currently hamstrung by the prevailing configuration. Potential price

impacts and related mitigation measures for industries also need to be considered. Therefore, Germany should adopt an open-minded approach and take evidence-based decisions regarding a potential bidding zone split.

6. Hasten the smart meter rollout to unlock the enormous potential of demand-side flexibility and distributed generation.

Germany has not to date taken advantage of the considerable flexibility solutions that demand-side management could provide to efficient power system operation. For households, as behind-the-meter resources (solar panels, heat pumps, electric vehicles) continue to surge, they represent an important opportunity to support efficient power system operation. In this regard, the government should quickly remove barriers to participation by households and aggregators that can unlock these services, including lowering regulatory hurdles or increasing incentives. For example, the government could look into grid fees of behind-the-meter home batteries and vehicle-to-grid charging. The rollout of smart meters will be a key enabler of demand response. Though recent reforms have set out a plan for ramping up smart meter deployment, the timelines should be accelerated, including by putting in place more measures to push smaller DSOs to ramp up deployment. Beyond just installing smart meters, regulations should also support access to and use of smart meter data for both consumers and grid operators. A shift toward time-of-use pricing and dynamic tariffs could also bring important cost savings for electricity consumers.

An important element to encourage behind-the-meter flexibility is improving the integration of consumer systems into the distribution grid. In the German context, ensuring that distribution grids are fit-for-purpose through the energy transition will be at least as important as expanding transmission grids. Moreover, efficient investment in distribution systems can, to some extent, reduce the need for transmission expansions. To this end, not only will the government need to address regulatory impediments for consumers, but it will also need to facilitate upgrades by (numerous and varied) DSOs, leveraging recent efforts at regional scenario planning. In addition, regulation to allow smart meters to be used by grid operators to control distributed photovoltaic supply should also be considered.

7. Jump-start the expansion of large-scale storage in optimal locations.

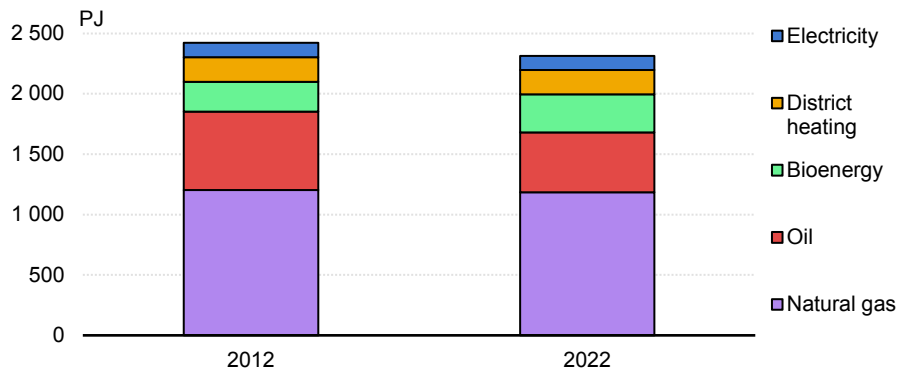
Considering the extent of variable renewables generation in Germany's electricity system, which already exceeded 60% in 2024 and is planned to be 80% in 2030, the country has relatively low levels of large-scale electricity storage (1.7 GW with 2.2 GWh in January 2025). Notably, battery storage can offer near-term solutions to grid management and flexibility services that grid expansions would take years (and substantial costs) to achieve. Recent reforms to allow storage to participate in frequency response and services markets bolster the market case for investments as will other efforts such as the grid booster initiative, innovation tenders and using storage for energy management at large industrial sites. Capacity under these programmes should be expanded and their applications broadened (to cover both grid stability and market participation) to promote faster deployment and ensure that there is a route to market for the required level of storage to support electricity system needs. The government could look to the Italian model under which the TSO TERNA will run utility-scale storage tenders targeting locations that are optimal for the system, as well as Ireland's Electricity Storage Policy Framework and related measures that support flexibility in systems with high levels of variable renewable generation. To further deliver on a more rapid buildout of storage assets, the government should also fast track the implementation of measures identified in its electricity storage strategy and accelerate grid connections to unlock projects in optimal locations awaiting connection (around 24 GW are considered to be viable out of a total of 160 GW requests) and remove barriers to the further construction and operation of pumped storage units. Supporting and investing in research on emerging storage technologies and boosting target volumes for long-duration energy storage will also be important enablers for increasing system stability and adequacy.

2. Decarbonising heating in buildings

It is clear that Germany will not meet its climate targets without accelerated action to decarbonise heating in buildings. The main driver for emissions in the sector is fossil fuel use in space and water heating. Besides a drop in oil consumption and a small increase in the use of bioenergy, the energy mix used for heating in buildings has not changed much in the last decade. In 2022, natural gas supplied 45% of energy used for space heating in Germany. Biogas, with more limited availability, will not be able to replace the current use of natural gas in heating, so an alternative solution to move away from the gas grid is needed. Furthermore, heating oil accounted for 24% of

energy consumption in residential space heating, indicating that large numbers of individual oil boilers will need to be replaced for Germany to decarbonise its residential heating sector. Decentralised heat pumps and district heating are the main options to replace fossil fuel boilers, but both account for relatively small shares of Germany's heating demand today.

Buildings sector heat sources in Germany, 2012-2022



Source: IEA (2024), Energy End-uses and Efficiency Indicators.

Replacing fossil fuels in heating also improves energy security. High dependence on natural gas became an apparent energy security and affordability concern during Russia's invasion of Ukraine and the following energy crisis. As a response to the energy crisis, Germany took several steps to prevent gas shortages, including developing new LNG and regasification infrastructure and implementing short-term energy-saving measures. Relying too much on fossil fuel imports has proven both risky and costly, and Germany is now taking additional steps towards decarbonising its heating systems, through both legislation and subsidies.

Policy spotlight: Long-term legislative framework for decarbonising heating

Germany established a clear legal framework for decarbonising heating in buildings by 2045. In September 2023, parliament approved the amended Buildings Energy Act, which requires new buildings as of 1 January 2024 to use at least 65% renewable energy in heating. For existing buildings, fossil fuel heating systems can still be installed but must meet renewable blending quotas starting in 2029. However, once a municipal heating plan is ready, by no later than mid-2028, all newly installed heating systems will be required to reach at least 65% renewable heat. Furthermore, the new legislation mandates that, as of 2045, all buildings must be heated in a climate-neutral way using only renewable energy.

Complementing the new Buildings Energy Act, the government introduced the Heat Planning Act, which also came into force in January 2024. The Act requires municipalities and regions to develop municipal heating plans that lay out how to make their local heating infrastructure climate-neutral, including where district heating solutions would be efficient. Large cities with more than 100 000 inhabitants have until 30 June 2026 to provide these plans, while smaller towns have a later deadline of 30 June 2028. A simplified heat planning procedure is possible for municipalities with fewer than 10 000 inhabitants. With this new legislation, Germany goes further than what is required in the EU Energy Efficiency Directive, which requires cities with populations over 45 000 to develop heating and cooling plans.

The overall framework, which sets clear targets and timelines for transitioning heating systems to low-emissions options, is a major accomplishment. Given that households typically use their heating systems for more than two decades, clarity on long-term legal expectations will help steer purchase decisions in the right direction. Likewise, the policy guidance provided by the two pieces of legislation also gives signals to the heat pump industry and district heating companies to undertake investments to ramp up capacity, infrastructure and supply chains.

Communication on heating strategies

The process for putting the Building Energy Act and Heat Planning Act into place was challenging. The initial proposal for the amendment of the Building Energy Act from April 2023 included a requirement on all new heating systems to use at least 65% renewable energy as of 1 January 2024. This was criticised for being costly for many households, and the proposal was further debated within the government. The final law that was passed softened the requirement to only apply to new buildings, until the preparation deadline for municipal heating plans (mid-2026 and mid-2028). This means that new oil and gas heating systems can continue to be installed for several years, which has been criticised by various experts and environmental organisations for not being ambitious enough for Germany to meet its climate targets.

Despite the challenges in getting the new regulation in place, it is still an achievement. Compared to the initial proposal, the final act will not achieve the same emissions reductions by 2030, but it sets Germany on the long-term transition toward carbon neutrality by 2045. However, heat pump sales and investments in district heating networks must accelerate, and recent market developments show lagging uptake. The government needs to focus on getting the right incentives in place for investments in new heating equipment and infrastructure while building trust with the population to participate in the energy transition. Moreover, the government will also need to more clearly communicate to the public the impact of fossil fuels prices from the German carbon price (and the ETS2 from 2027), which will steadily increase the costs of running fossil fuel boilers.

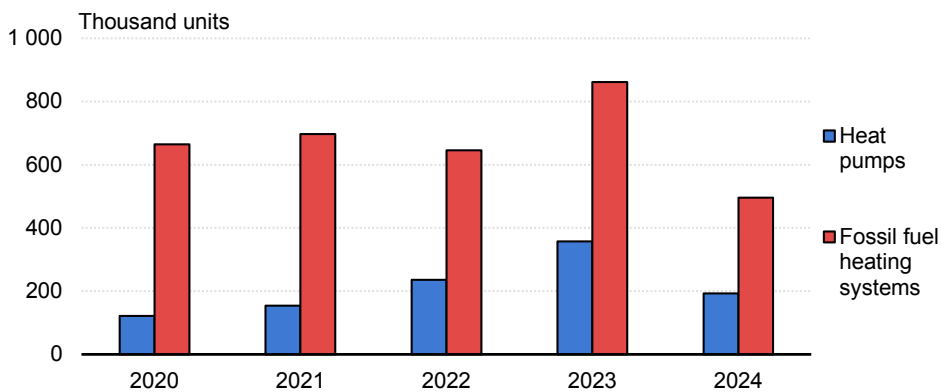
Heat pumps

Heat pump deployment has increased for several years, and it is the primary heat source in new buildings. The market for heat pumps grew by over 50% per year in 2022 and 2023, driven largely by record high gas prices as well as 2022 reforms to shift green levies away from electricity prices. In 2023, around 350 000 heat pumps were sold, and Germany is targeting 500 000 new installations per year as of 2024. Almost two-thirds of the residential buildings built in 2023 will use heat pumps as their primary heating source and over three-quarters of new building permits issued in 2023 would use heat pumps.

However, recent trends show a drop in heat pump sales, and Germany is behind on its targets. The market struggles with unfavourable electricity prices compared to natural gas and lack of consumer confidence, partly due to the lengthy process to

arrive at a political framework for decarbonising heating. Sales of fossil fuel boilers increased in late 2023, as natural gas prices softened, and many people decided to replacement existing boilers ahead of the proposed amendments to the Building Energy Act; this trend continued in the first two months of 2024. After that, the whole market for heating devices dropped probably due to uncertainties on the Building Energy Act and previous pull-in effects in 2023. Recently published figures from the Association for Efficiency and Renewable Energies for 2024 show that 193 000 heat pumps were sold in 2024, compared to 356 000 in 2023, far short of the targeted number of 500 000.

Heating system sales by type in Germany, 2020-2024



Source: IEA analysis based on Association for Efficiency and Renewable Energies (2025), Heating systems: Sales fell by half in 2024 (Accessed: 30 January 2025) and Sales of heating systems decline sharply: Heat transition stagnates (Accessed 31 October 2024).

Several potential barriers to heat pump adoption exist[1]. These include high upfront costs for equipment and installations, uncompetitive electricity prices, other non-cost hurdles to consumer adoption (such as complexities in multi-family buildings) and insufficient installation capacity. Germany has taken steps to address these issues, though more systematic action will be required across all areas to improve results.

[1] See Chapter 3 of IEA (2022), The Future of Heat Pumps.

Financial support

Germany supports heat pump deployment with financial incentives to address higher upfront costs. Through the Federal Funding for Efficient Buildings, the government provides financial support for investments in climate-friendly heating systems. A homeowner can be reimbursed for 30-70% of the investment costs, with higher shares for low-income households and if the replacement takes place before 2029. As of 1 September 2024, the subsidy was available to all building owners, including landlords of condominiums and municipalities.

Moreover, to address the split incentive challenge between tenants (who are not incentivised to take on upfront installation costs) and landlords (who do not benefit from lower energy bills), Germany is allowing landlords to pass through 10% of a new heating system's costs onto a tenant's rent, with a limit of 0.50 EUR/m².

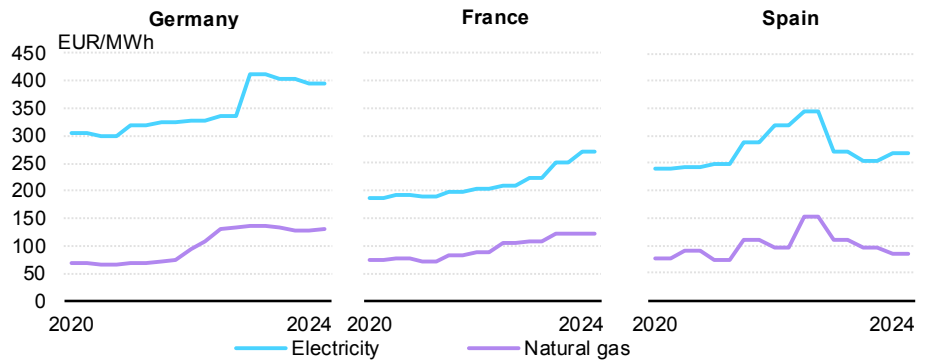
Nonetheless, bureaucratic hurdles to the complex documentation required to access available funds along with information asymmetry to households have served as notable obstacles.

Uncompetitive electricity prices

Energy prices and taxation still seem to favour fossil fuel alternatives over heat pumps. German households paid the highest electricity price among 27 EU member countries in the second half of 2023, and the seventh-highest share of taxes and levies on electricity. By comparison, for natural gas prices, German households pay around the median among EU countries. The average household electricity price in the second half of 2023 was 0.40 EUR/kWh, compared to around 0.12 EUR/kWh for natural gas.

Even with the high efficiency of heat pumps compared to fossil fuel boilers, the price differential between electricity and natural gas still makes gas boilers a financially attractive option for German consumers. Even though heat pumps might have lower total costs over their life cycle compared to gas-based heating systems, this is not clear to consumers and does not seem to convince homeowners to make heat pump investments today. The German Heat Pump Association wants to see a reduction of the electricity tax to the minimum under European law to create a more level playing field for heat pumps. Industry experts estimate that electricity prices should be no more than 2.5-3 times those of natural gas to encourage heat pump sales.

Quarterly electricity and natural gas prices for residential users in Germany, France and Spain, Q1 2020-Q2 2024



Source: IEA (2024), Energy Prices.

Non-cost barriers and supply chains

Non-cost barriers to heat pump adoption can include lack of information and complicated approval processes. Consumer platforms, such as the One Stop Shop service in Ireland, can make it easier for homeowners to invest in home energy improvements, including heat pumps. Providing online comparison tools is another way to simplify the process for consumers by making information on heat pumps and installer options more accessible.

A shortage of qualified installers is another potential barrier to heat pump deployment. The German Heat Pump Association developed qualification measures for trainees and for professional installers. Similarly, the German Central Association Plumbing, Heating, Air Conditioning (ZVSHK) launched a three-year project with the aim to significantly shorten the installation times for heat pumps, to better meet growing market demand with available skilled workers. Incorporating heat pumps into existing certifications for plumbers and electrical engineers, who have similar skills, could also help solve the issue. Additionally, BMWK set up a funding programme subsidising training measures for planners and installers of heat pumps.

The growing heat pump market can bring business opportunities as well as supply chain challenges. Supply chain bottlenecks affecting components such as copper or computer chips can lead to increased manufacturing costs and a slower deployment

rate for heat pumps. However, there are also business opportunities for the German industry that supplies heat pumps or parts used in heat pump manufacturing. Heat pump manufacturers such as Daikin and Stiebel-Eltron as well as the country's largest semiconductor producer Infineon have made announcements for large investments to expand production capacity.

Germany's distribution grids will also require updating to accommodate heat pump uptake. Given that the country's heating has historically been sourced mainly from fossil fuel boilers, local distribution grids are, in many cases, not equipped to manage the surge in electricity demand that will come from heat pumps (combined with EVs). As a result, forthcoming municipal heating plans will need to be co-ordinated with DSOs to ensure a smooth integration and optimisation of demand-side resources to manage local grids.

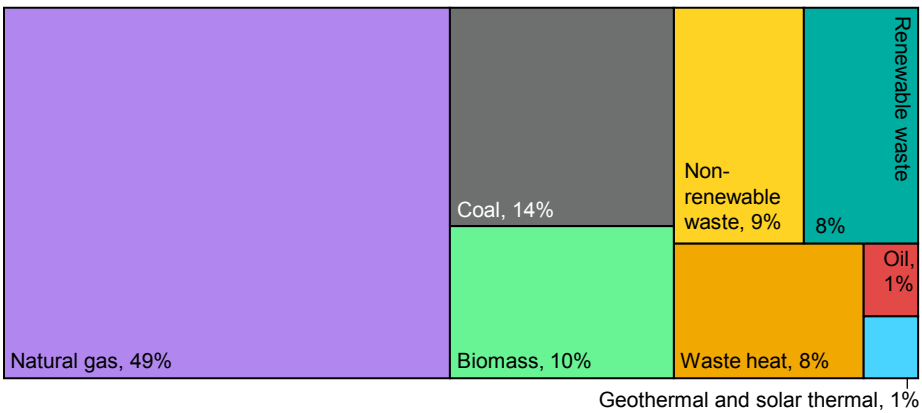
The district heating market

The significant growth potential of district heating can play an important role in decarbonising heating. The government presented ambitions for adding 100 000 new district heating connections per year. According to the industry association AGFW, up to 20 million of Germany's roughly 43 million households could be connected to district heating networks by 2045 if the government introduces the right subsidies and framework conditions. However, the significant upfront investment and complex stakeholder engagement and co-ordination required for infrastructure and the high dependence on urban planning are major challenges for market development.

Decarbonising district heating supply

District heating systems must phase out the use of fossil fuels and support waste heat integration to provide the low-emissions heat needed to decarbonise heating. The share of renewable energy used in the district heating supply in Germany is increasing and the new Heat Planning Act set a legal requirement for each district heating network to use at least 30% renewable or unavoidable waste heat by 2030, with exceptions for some district heating networks that need to reach this level by 2035. By 2040, the share of renewables or unavoidable waste heat in each district heating network must be 80%, compared to a national average of around 35% today.

District heating generation by energy source in Germany, 2024



Note: Data are preliminary.

Sources: IEA based on German Association of Energy and Water Industries (2024), Energy supply in 2024 (Accessed 1 April 2024).

While the Heat Planning Act sets a framework for clarifying the need for new district heating systems, investors may require stronger incentives to make the necessary infrastructure investments to realise the heating plans. In 2022, the government launched the Efficient Heat Networks scheme to support investments in expanding and decarbonising pre-existing district heating networks and erecting new district heating networks that use at least 75% input from renewable sources or waste heat, to increase the use of renewable energy and waste heat in the heat supply. In the draft budget plans from August 2024, the government allocated EUR 3.4 billion between 2025 and 2029 to the Efficient Heat Networks scheme. However, one consultancy report done on behalf of the district heating industry associations claims that the planned expansion of district heating in Germany will require EUR 43.5 billion in investment by 2030, and needs state support of EUR 3.4 billion per year. Furthermore, the support needs to have a long-term perspective and provide the necessary stability for market actors taking investment decisions.

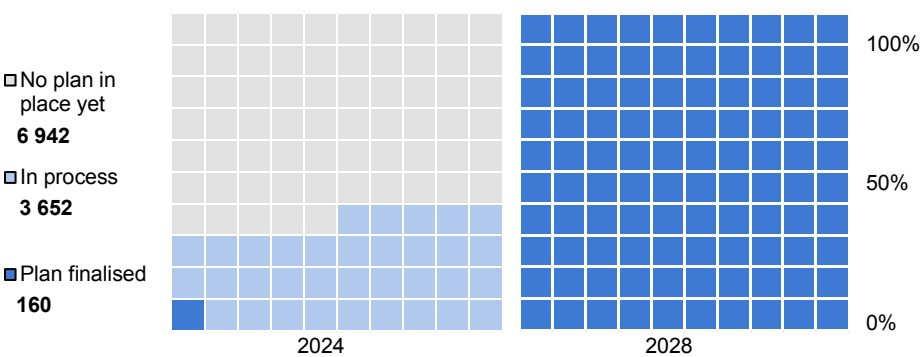
Planning district heating

District heating is a collective infrastructure solution that requires large investments and many connected customers to be cost-effective. A benefit of district heating is

that it can use available heat sources more efficiently than individual heating systems, including residual waste heat from industries, wastewater treatment, data centres and other facilities. Mapping out such heat sources and the demand for heat in a country is an important step to be able to develop resource-efficient and cost-effective heating solutions.

With the new Heat Planning Act, German municipalities are required to present municipal heating plans. Energy Cities, a European network, gives this legal framework the highest score in terms of how it implements the EED requirements. However, Germany scores lower in terms of the support framework to implement the regulation, as it varies significantly across the country. For the heat plans to be a successful tool in developing district heating networks and decarbonising heating, municipalities need to have sufficient knowledge and resources. To that end, in July 2024, Germany initiated a stakeholder dialogue on heat planning with the objective to identify measures on both the local and regional levels for enabling municipalities to develop well-considered heating plans.

Status of municipal heat planning (2024) and target (2028) in Germany



Note: Each grid represents 1% of all German municipalities required to develop a municipal heating plan.

Source: IEA analysis based on KWW (2025), Overview of municipal heat planning available (Accessed 27 January 2025).

Although the heat plans are done on a municipal level, state and federal co-ordination will also be needed to avoid sub-optimised solutions. Tools and examples from other countries can also be used for inspiration. Denmark has done similar heat planning

since the first Danish heat supply law in 1979, which resulted in a significant share of district heating in residential heat supply. Germany can continue to build on the Competence Center for Heat Transition, which is an established platform at the federal level to support municipalities with guidelines, best-practice examples, trainings and networking opportunities. Germany also needs to ensure that municipalities are equipped with the necessary skills and expertise to develop strategic heating plans.

To further speed up planning processes for district heating, representatives from associations of towns and municipalities, cities, and counties have asked for district heating networks to be classified as an "overriding public interest". This was implemented through the Heat Planning Act, which states that construction and operation of district heating networks and associated installations are of overriding public interest.

Regulatory framework

The German district heating market has no price regulation, and consumers are bound to natural monopoly suppliers, often on long-term contracts. While prices for other sources of heating declined in 2024, district heating prices increased significantly. The recent price developments in the district heating sector have led to legal proceedings by the Federation of German Consumer Organisations and investigations by the Federal Cartel Office.

The Monopolies Commission, an independent expert committee advising the German government on competition and regulation, has proposed changes to improve competition on the heating markets. In its Competition 2024 report, it compared price data in 85% of Germany's district heating networks and found evidence of a low level of competition between district heating and other heating systems. The Monopolies Commission recommended the introduction of a central transparency platform where consumers can compare prices. It also recommended further developing the existing price regulation framework so that district heating prices better reflect developments in the general heating market. Alternatively, the Commission suggests a price cap regulation to limit district heating prices.

The government is currently working on a revised regulatory framework for district heating to increase the transparency of pricing models and price setting. The German Association of Energy and Water Industries (BDEW) recently launched a district heat price comparison platform to increase price transparency. A similar industry initiative

is the Swedish Price Dialogue, which has been in place since 2011 and gathers large shares of the district heating industry and the biggest customers to discuss price changes on the district heating market.

Recommendations

8. Co-ordinate and advance municipal heat planning to enhance the value for stakeholders.

With the Heat Planning Act, Germany made tremendous progress toward providing clarity on the energy transition needed in the heating sector. In 2026-28, close to 11 000 municipalities will present plans for how to decarbonise their heating systems. This presents a critical opportunity for the government, consumers and industry stakeholders to take stock of the situation and take strategic decisions on policy development and investments. It equally presents an opportunity to engage with consumers and with citizens more actively in the energy transition. Notably, the plans are expected to provide important bottom-up clarity on the optimal mix for energy efficiency, electrification, district heating (including the role of waste heat) and other direct renewable heat. The government should capitalise on this opportunity by supporting and co-ordinating timely development of the plans at the federal level and ensure sufficient resources for all levels of government to develop, assess (where necessary) and implement the plans. Similarly, regional co-ordination on implementation of the plans can be necessary for optimal resource allocation. The heat planning should also be aligned with other energy system planning, such as regional electricity network development plans. Following an assessment of the first round of plans, the government might consider making the updated plans (due after five years) more binding to drive investments. Furthermore, the government may consider aligning the plans with existing funding schemes directed at heating technologies and explore possibilities to use heat plans as the basis for large-scale technology procurement. Lastly, the effort to develop the plans should also be used as an opportunity to consider plans for cooling networks, whose needs will grow in the coming years.

9. Send clear signals that heat pumps and district heating paired with energy efficiency will be the primary option to decarbonise heating in buildings.

As a starting point for decarbonising individual homes, the government should support energy efficiency upgrades in conjunction with the rollout of heat pumps and connections to district heating. Toward this end, the government should back the role of energy advisors in helping homeowners undertake renovations and install heat pumps (or other renewable heating systems). Electricity will be the most efficient and scalable option for decarbonising heating, especially in decentralised heating systems. The strategy to expand heat pumps should be mindful of the valid affordability concerns of homeowners. Therefore, complementary to its messaging around heat pumps being the preferred technology option for decarbonising heating, the government should clarify to consumers the policy measures that will help support the deployment of heat pumps to alleviate household concerns over upfront and operating costs. Though the government does not promote the use of hydrogen in home heating systems under its hydrogen strategy, the "technology-neutral" approach applied in the Buildings Energy Act can be perceived as sending mixed signals about the possible application of hydrogen in home heating, thereby delaying the investment case for switching to heat pumps today. As such, the government should pursue clear and explicit messaging that electrification will be the viable pathway for future decentralised heating systems. Relatedly, to avoid a lock-in effect to fossil fuel boilers, the government should also communicate to households the longer term business case for heat pumps and connections to district heating in a context where CO_2 prices for heating fuels will rise (under the ETS2) and electricity prices are expected to fall (including through government efforts to alleviate fees and taxes).

3. Expanding the role of hydrogen

As a major industrial powerhouse, hydrogen will be a core pillar to meeting Germany's climate targets. Already, Germany is the largest consumer of hydrogen in Europe, mainly used by refineries and chemicals producers. Hydrogen will play a bigger role in Germany's future energy system, including for decarbonising certain segments of the industry and heavy transport sectors, where electrification is either infeasible or too expensive.

Toward this end, the German government laid out detailed strategies and plans to develop a hydrogen sector, covering the full range of the hydrogen value chain. Fostering demand in key end uses will be a crucial starting point, and financial support measures will be necessary to achieve this. Moreover, while Germany will support a certain amount of domestic renewable hydrogen production to nurture the early years of hydrogen development, the bulk of its consumption will need to be met by imports, given limitations on renewable electricity supply. Therefore, creating enabling conditions for imports, including supporting infrastructure, will be an overriding imperative.

Germany is off to a good start and already has a detailed strategy with clear targets and timelines. The next step for Germany is to ensure that policy measures lead to timely investments that jump-start the hydrogen sector in the 2030 time frame. In addition, where Germany has taken a broad stroke approach to promoting all parts of the hydrogen value chain, it will need to take a closer look at its specific competitive advantages in relation to other producers and end users.

National Hydrogen Strategy

Germany set a clear strategy for hydrogen and introduced policy to support its development. The government adopted the National Hydrogen Strategy in June 2020, with a focus on low-emissions hydrogen deployment to reduce process-related emissions in the steel and chemicals industry as well as to replace fossil fuels in certain parts of the transport sector. The strategy – toward which the government allocated EUR 7 billion of public funds in June 2020 – notes the opportunity that hydrogen offers to promote Germany's industrial capabilities and boost its export competitiveness. It focused on establishing the first phase of a renewables-based hydrogen rollout by 2023, laying out an action plan to motivate private sector investment in production, transport and consumption. It also highlights the role that international co-operation will play, especially among European countries, including through the creation of common sustainability and certification standards. The government also launched a National Hydrogen Council in 2020, which comprises a cross-section of relevant stakeholders (companies, research institutions, environmental organisations and trade unions) to offer independent assessments and advice to the government on the development of a hydrogen economy.

In 2023, amid the energy crisis, the strategy was updated and made more ambitious to ramp up the development of a hydrogen economy. The National Hydrogen Strategy Update strengthened the target for domestic installed electrolyser capacity to 10 GW

by 2030, compared to the previous target of 5 GW. The 2023 Update also outlines goals for infrastructure, demand and regulation. In line with those goals, BNetzA approved in October 2024 a plan for a hydrogen core network of 9 040 km pipelines with total investment costs of EUR 18.9 billion by 2032. The Plan consists of repurposed and new hydrogen pipelines and includes the IPCEI of the European hydrogen programme. The update also aims to stimulate demand for hydrogen in various end-use sectors, especially industry and heavy transport, as well as to support Germany in becoming a leading provider of hydrogen technologies by 2030. It also calls for the creation of an appropriate regulatory framework at the national, European and international levels to support the development of a well-functioning global market.

To realise the 2030 goals under the updated strategy, the government has committed to an implementation plan along four focus areas: 1) ensuring sufficient availability of hydrogen; 2) developing hydrogen infrastructure; 3) implementing hydrogen applications (e.g. industry, transport); and 4) creating effective framework conditions. As part of this effort, the government is examining current regulatory barriers and identifying legal options for simplification and acceleration of permit issuance across the hydrogen value chain.

Policy spotlight: Hydrogen auctions

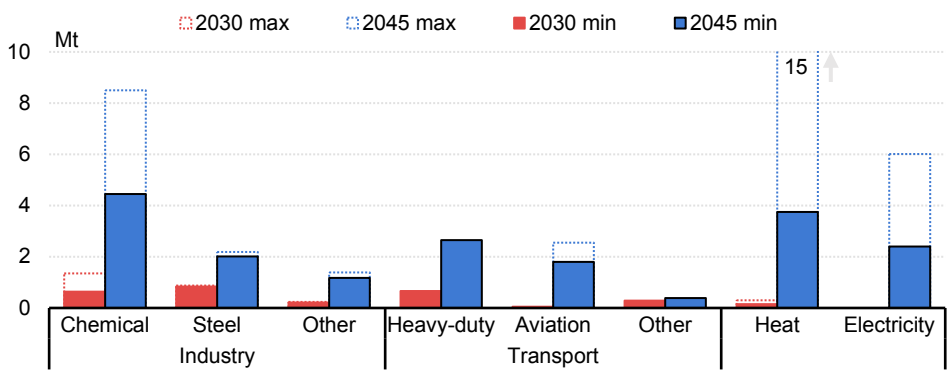
To accelerate the development of a hydrogen market, Germany launched the H2Global mechanism in 2022. H2Global operates as a double auction through an entity (Hintco, a subsidiary of H2Global Foundation) that serves as an intermediary between buyers and sellers who face challenges connecting during the early phases of market development. First, an auction procures ten-year contracts for hydrogen on the global market, then a second auction resells the hydrogen at competitive prices to EU buyers, usually under one-year contracts. The government subsidises the cost differential between the two auctions. The first auction for ammonia, synthetic methanol and synthetic kerosene from renewable hydrogen took place in late 2022 with a budget of EUR 900 million for deliveries at the end of 2024. The government plans an additional EUR 3.5 billion in funding for future auctions for hydrogen and its derivatives over the period 2027-36. The programme represents one of the strongest, market-based policies to support hydrogen trade in the world, and can serve as an example to other countries.

Germany's auction programme is closely integrated with the European Union. In 2023, the government reached a deal with the European Union to link the H2Global mechanism with the external leg of the European Hydrogen Bank. Under the deal, H2Global will be open to all EU governments that wish to participate in its hydrogen tenders. It will also co-operate with the European Hydrogen Bank on joint European tenders in the external leg to improve the buying power for European importers on the global market (the first auction in April 2024 in the internal leg allocated EUR 720 million to seven European projects). Furthermore, in November 2023, Germany and the Netherlands signed an agreement to provide EUR 300 million each in a joint tender for renewable hydrogen starting in 2027. Germany is also signing deals under H2Global further afield. A recent memorandum of understanding with Canada (EUR 200 million) and a joint declaration of intent with Australia (combined EUR 400 million) are testament to the programme's growing popularity with partner suppliers.

Demand outlook

Germany foresees accelerated demand growth for hydrogen by 2030 and 2045. The 2023 National Hydrogen Strategy Update forecasts that, relative to 2023 demand of around 55 TWh, Germany's demand for hydrogen will roughly double to 95-130 TWh per year by 2030, and again nearly triple to 350 TWh in 2045. The figures align with forecasts released by the National Hydrogen Council, which in 2024 upgraded its estimate of hydrogen demand to 94-125 TWh by 2030, mainly from the steel and chemicals industries as well as heavy-duty transport, a sizeable jump from the previous year's forecast.

Hydrogen demand projections by sector in Germany, 2030 and 2045



Source: IEA analysis based on National Hydrogen Council (2024), Update 2024: Greenhouse gas savings and the associated hydrogen demand in Germany (Accessed 28 January 2025).

Certain hard-to-abate end-use sectors are expected to see the strongest demand for hydrogen. In particular, the National Hydrogen Strategy Update expects the industry sector to be the dominant source of hydrogen demand in the 2030 time frame, followed by transport. The strategy notes that widespread use of hydrogen is not foreseen in the heating sector, though Germany will continue to pursue legal and technical options to repurpose gas distribution networks for hydrogen and to develop decentralised hydrogen boilers. The update outlines short-term (2023), medium-term (2024-25) and long-term (up to 2030) measures to support hydrogen in each end-use sector.

A major cause of industrial emissions in Germany is the use of fossil fuels (especially natural gas) in industrial processes. While electrification may be viable for lower temperature process heat, it is either not feasible or not economical for high-temperature applications, which is particularly salient in the steel and chemicals sectors. Hydrogen will, therefore, play an essential role in decarbonising industrial process heat, which is a key focus area for the government's National Hydrogen Strategy. Hydrogen can also be used to replace fossil fuels as feedstock in industrial processes, such as steel production from iron ore, which conventionally uses coal to react with oxygen molecules, resulting in process-related CO_2 emissions.

The Hydrogen Strategy notes the need for financial support during the early stages of market development along with fostering markets for low-carbon products to encourage demand. Short-term government support measures include: financial assistance to companies to cover the higher costs of low-emissions technologies (e.g. via the Carbon Contracts for Difference programme), funding through the IPCEI Hydrogen programme and support through the Federal Fund for Industry and Climate Action.

In total, a budget of EUR 14 billion has been allocated to the IPCEI Hydrogen programme. Until the end of 2024, after state aid approval of all four "waves" by the European Commission, a large majority of the German projects (4 technology projects, 24 infrastructure projects, 3 mobility projects) were awarded funding. Also, six projects received funding based on the Climate Environment and Energy Aid Guidelines and General Block Exemption Regulation (including four projects aimed at converting steel plants to run on hydrogen).

Complementing the financial mechanisms, BMWK set out a strategy to support the development of lead markets for climate-friendly basic materials (starting with steel and cement) by establishing definitions and stimulating demand through public procurement. Rising EU ETS prices, especially leading up to and after the phase-out of free emissions allowances to industrial participants, will also be a major driver.

Transport is also expected to be an important application for hydrogen, and therefore a driver for ramping up the hydrogen economy. While passenger and heavy-duty road transport is largely expected to be decarbonised through electrification, shipping and aviation are expected to rely on hydrogen and hydrogen-based fuels. To support the development of a hydrogen market for the transport sector, the government plans to issue a master plan with detailed actions and timelines for hydrogen and fuel cell technology in transport. EU regulations are anticipated to support market

development in Germany, such as tightening CO_2 emissions reduction targets for heavy-duty commercial vehicles. Based on the requirement to cut CO_2 emissions by 90% in 2040 from 2019 levels, the National Hydrogen Council estimates Germany would see around 300 000 hydrogen trucks on its roads, resulting in 88 TWh of hydrogen demand. Still, battery electric trucks are expected to remain the dominant technology for zero-emission heavy-duty vehicles, with a predicted market share of 48% of new registrations in Germany in 2030. Hydrogen-powered vehicles with fuel cells and combustion engines are projected to be just under 20%. In addition, the National Hydrogen Strategy Update notes that the inclusion of sub-targets for hydrogen in the revised EU RED II will be an important driver. Regulatory frameworks are expected to support the development of electricity-based power-to-liquid (PtL) aviation fuels and refuelling infrastructure for liquid hydrogen (such as a PtL paraffin quota at the EU level and sub-quotas in the ReFuelEU Aviation and ReFuelEU Maritime initiatives). The government also plans to offer support through various funding programmes, including for technological research, innovation and deployment across the transport value chain. Already, Germany has seen an uptick of interest in fuel cell electric vehicles for trucks and buses, along with hydrogen fuelling stations.

Hydrogen is also expected to play an important role as an energy carrier in a renewables-based power system. In particular, it can provide a crucial function in storing and transporting energy from renewable sources. As coal and natural gas-based electricity generation are phased out of the system, hydrogen power plants are also expected to play a role in addressing short-term and seasonal balancing needs in the electricity system. Therefore, new natural gas-fired plants are meant to be outfitted to convert to hydrogen use at a later date. In 2022, the government amended the Combined Heat and Power (CHP) Act so that new co-generation plants with at least 10 MW of capacity must demonstrate hydrogen-readiness at relatively low costs. The Renewable Energy Sources Act includes a similar requirement for biomethane-fired plants that are funded from 2023. BMWK forecasts that the electricity and heat sectors will drive approximately 80-100 TWh of hydrogen demand by 2045.

Relative to other sectors, hydrogen is expected to play a more marginal role in heating for buildings, where more economical options exist. The National Hydrogen Strategy Update notes that direct use of hydrogen for space heating will only take place after 2030, though hydrogen boilers or hydrogen co-generation systems might be necessary for decentralised buildings. It also recognises that the potential for using waste heat from electrolysers should be considered in the siting of electrolysers.

Supply outlook

Germany has established ambitious targets for hydrogen production, but the bulk of demand will be met by imports. The National Hydrogen Strategy Update increased the target for domestic electrolyser capacity from 5 GW to 10 GW by 2030. The intention of domestic production capacity is to stimulate the creation of a market for low-emissions hydrogen and meet demand with short transport routes. Germany is off to a good start in this regard, being one of the frontrunners in Europe from a production perspective. Meanwhile, the National Hydrogen Council estimates that its projected range of 2030 demand would require 39-52 GW of electrolyser capacity, coming from either domestic sources or abroad.

In the 2030 time frame, various types of low-emissions hydrogen will be considered. Whereas the original strategy only focused on hydrogen produced from renewable energy, the update takes a broader technology approach, making room for other types of low-emissions hydrogen (including using natural gas with carbon capture and storage [CCS]) to help speed up the development of a hydrogen market. However, a certain amount of so-called grey hydrogen (produced from natural gas without CCS) is expected to continue to play a role in the 2030 time frame, especially in the chemical sector. Direct financial support, however, will only be available to renewables-based hydrogen, while other types of hydrogen would be supported in end uses.

The government has laid out a clear plan for support measures that will help meet the 2030 electrolyser target of 10 GW. This includes support for research and development along with direct funding for electrolysers, as well as implementation of EU directives (notably the amended RED II) to stimulate demand and debottleneck planning and approval processes. In particular, state tenders and the IPCEI Hydrogen programme are expected to play large roles. Moreover, offshore wind energy development is also expected to supply electrolyser capacity. Specifically, the Wind Energy at Sea Act includes a provision for 500 MW of electrolyser capacity to be tendered annually over the period 2023-38 to produce low-emissions hydrogen that supports the electric grid.

However, production capacity is still lagging behind targets. According to a recent report by E.ON, final investment decisions are not keeping pace with planned projects. The report notes that to realise the 2030 target, all announced projects would need to materialise as planned. However, to date only 19 final investment decisions have been taken out of 88 planned projects, amounting to just 1 GW of electrolyser

capacity. Some of the challenges highlighted include continued uncertainties over certifications and standards as well as insufficient funding, along with a lack of storage and transportation infrastructure. Though the government is taking action in all these areas, an acceleration of investments in production capacity is needed to meet the targets.

Imports will play an outsized role in Germany's hydrogen supply, accounting for around 50-70% of supply in 2030, and more thereafter. In the 2030 time frame, the government expects most hydrogen and derivatives imports to arrive via ship, while beyond 2030, pipelines are foreseen to play a bigger role. Infrastructure development, therefore, will be crucial to support the ramp-up of imports into Germany (see below). The National Hydrogen Strategy calls for the development of a hydrogen import strategy (see below), whose aim is to set up diversified import strategies and avoid new dependencies.

International partnerships on hydrogen supply will need to be stepped up to meet domestic needs. Toward this end, Germany has already entered into a number of agreements and partnerships with several countries, including Australian Canada, Norway and the United Arab Emirates. However, the global market for hydrogen imports will likely be highly competitive for the foreseeable future. While some expected large producers will consume most of what they produce (China, the United States), others will look to capture more value through the supply chain, preferring to export sponge iron for steel production or ammonia for chemical production rather than hydrogen. Hydrogen imports will mostly take place through pipelines, whereas hydrogen derivatives can rely more on seaborne trade. Given the high costs associated with hydrogen pipelines, realistic hydrogen import options for Germany will be closer to home (mainly within Europe), while derivative imports could come from further afield. However, even within Europe, plans for hydrogen pipelines are facing challenges, as evidenced by Equinor's September 2024 decision to suspend a connection project to Germany due to high costs and inadequate demand.

In July 2024, the Federal Cabinet approved an import strategy for hydrogen and hydrogen derivatives. A core pillar of the import strategy is to ensure sufficient domestic demand to support production elsewhere. Moreover, the strategy also places a strong emphasis on international partnerships, especially within the European Union and its neighbouring countries (such as Norway, the United Kingdom and North African countries). It also calls for the development of a trans-European pipeline network. It notes the importance of geopolitical conditions, which underpin

the need to ensure a diversified portfolio of reliable suppliers, including from developing and emerging countries to support their economic development.

Infrastructure

One of the largest enablers of a hydrogen market will be supporting infrastructure. Therefore, infrastructure forms a central pillar of both Germany's hydrogen strategy and its import strategy. The government is taking steps to accelerate the deployment of infrastructure. A draft of the Hydrogen Acceleration Act passed in May 2024 lays out the legal framework for accelerating the development of hydrogen production, storage and import. It notably includes measures to streamline and fast track planning and approval processes for hydrogen infrastructure. The Act is expected to be adopted in the upcoming legislative term.

Pipelines

The existing gas network is a good starting place to efficiently build up hydrogen infrastructure. The government considers repurposing of existing natural gas pipelines to be the most cost-effective and fastest option for building out a hydrogen network. Already, the Energy Industry Act provides a regulatory framework and compensation mechanism for repurposing gas lines, which will be adapted based on implementation of the EU regulatory framework for gas and hydrogen. However, the hydrogen network will not be built to mirror the extensive natural gas network, but rather to consider the creation and location of hydrogen hubs (with supply facilities and offtakers) that might warrant dedicated infrastructure.

With the Hydrogen Core Network, the German government aims to connect key hydrogen supply, demand and storage locations. In a major step forward, BNetzA, based on a law establishing a legal and regulatory framework for the development of a domestic hydrogen network, has approved the plan for a hydrogen core network of 9 040 km of pipelines with total investment costs of EUR 18.9 billion (including under the IPCEI hydrogen programme) and planned construction by 2032. The core network will consist mainly of repurposed gas pipelines (60%) and include 15 interconnection points. The feed-in capacity would be 100 GW and the feed-out capacity 87 GW.

As a next stage, the precise construction path of the Hydrogen Core Network will be further developed with a comprehensive network development planning exercise. It will be carried out in an integrated process with natural gas network development planning to account for interactions and synergies across the systems. It will also

closely link to the planning process for electricity grids, to ensure sufficient grid capacity for electrolysers and efficient use of hydrogen storage to provide flexibility.

The Energy Industry Act (EnWG) established integrated network development planning for natural gas and hydrogen and the necessary legal and regulatory framework has been put in place. As part of an integrative process, TSOs and regulated operators of hydrogen transport networks draw up a scenario framework every two years and, based on this, a network development plan for gas and hydrogen.

If the scenarios indicate delayed demand for hydrogen and consequently that some pipelines might be needed later than expected, a flexibility option allows BNetzA to postpone the commissioning of individual lines that have already been approved as part of the core network, until 2037. The flexibility option is not meant to be a postponement of the Core Network, but rather to offer the possibility of putting lines that have already been approved into operation later. The aim of the flexibility option is to avoid potential vacancies and thus keep grid fees low, which is a basic prerequisite for a successful hydrogen market ramp-up. This enables a demand-orientated network expansion that evolves with the market ramp-up, into which current findings and market developments can be incorporated.

European connections will be the priority. Following the buildout of the German core hydrogen network in 2032, Germany's hydrogen strategy plans for connections to EU countries through the European Hydrogen Backbone. The first phase of the Backbone will be underpinned by infrastructure projects financed with the IPCEI Hydrogen framework, which includes ten German hydrogen pipelines. A planned pipeline between Germany and Denmark is still moving forward, after the timeline was pushed back by three years to 2031 (a first buildout is now re-scheduled for 2030). Germany has also signed declarations of intent with the Netherlands for cross-border hydrogen infrastructure (as well as a joint tender for hydrogen procurement through H2Global). In addition, Germany is at various stages of discussions and partnerships for offshore pipelines with the United Kingdom, Baltic countries and Iberian countries. However, despite an agreement reached between Germany and Norway in 2023, Equinor cancelled a planned pipeline to send up to 10 GW of hydrogen to Germany annually due to insufficient demand. Germany is also thought to have considerable potential for hydrogen storage for Europe in its vast salt caverns, together with its sizeable natural gas storage facilities that could be repurposed for hydrogen storage. German company Uniper is currently undertaking a trial project for hydrogen storage in a former salt mine, with plans to expand capacity to up to 600 GWh by 2030.

Policy spotlight: Hydrogen infrastructure financing

An amendment to the Energy Industry Act, finalised in April 2024, establishes the regulatory framework for financing the Hydrogen Core Network, in particular to steer the way that construction and operating costs are passed on to users. It allows network operators to charge lower fees to the limited number of initial system users and make up the lost revenues through a special amortisation account, managed by a special purpose vehicle that includes all core network operators. A state-owned bank (KfW) provides a credit line for the amortisation account to cover for the initial losses. As use of the network increases, so does the income from the grid fees. Any additional revenue generated will be returned to the amortisation account and will offset the initial shortfall in revenue by 2055 at the latest. If the amortisation account is not balanced by 2055 for reasons that cannot be foreseen today, a subsidiary state guarantee will take effect. The federal government will then make up the remaining shortfall and the operators of the hydrogen core network will contribute a deductible of up to 24% to make up the shortfall. The amortisation account is set up to have a long amortisation period, until 2055, to ensure full financing from grid fees even if the hydrogen ramp-up is delayed. Depending on market progress, the government has the option to terminate it from the end of 2038 and the subsidiary state guarantee will take effect.

In the pursuit of efficiency, the integrated network development planning process for natural gas and hydrogen takes place every two years. This allows for use of the flexibility option to postpone individual pipelines of the Hydrogen Core Network to avoid potential vacancies and thus keep grid fees at a low level, which is a basic prerequisite for a successful hydrogen market ramp-up.

The chosen financing model represents an innovative approach to financial risk sharing in the early years of market development by enabling private investment in infrastructure in a period marked by uncertainty about the pace of the hydrogen ramp-up. It attempts to alleviate the first-mover disadvantage by providing government-backed guarantees of stable returns.

The EU Gas and Hydrogen Internal Market Package, adopted in May 2024, will further establish the legal framework for building and financing hydrogen pipelines. To date, there has not been an uptick in the construction of hydrogen pipelines following the passage of a regulatory framework, though there was notable growth in planned investments in 2024.

Shipping

Germany also expects to receive imports from outside of Europe, by ship, especially for hydrogen derivatives. Seaborne hydrogen derivatives will be particularly salient in the early years before a pure hydrogen economy takes off. For this purpose, terminal capacity to receive imports needs to be increased. Germany's planned new onshore LNG import terminals are also designed to accept deliveries of hydrogen derivatives. Germany's 2024 National Port Strategy is aligned with the National Hydrogen Strategy and designed to upgrade the nation's port infrastructure, which is seen as losing competitiveness. However, industry stakeholders criticised the plan for lacking clear targets and timelines as well as financial support to co-finance infrastructure expansions and upgrades.

Germany is already seeing growing ammonia demand in the industrial sector. As a result, several projects for ammonia import are planned in Germany, which are expected to be operational between 2027 and 2030. Norwegian company Yara International opened a terminal with up to 3 million tonnes ammonia import capacity per year in Brunsbüttel in October 2024. If not used directly, then equipment (crackers) is required to convert ammonia to hydrogen (conversion losses can be significant). The same applies for methanol, while liquid hydrogen transport costs are assumed to remain prohibitively high for the foreseeable future.

Electricity

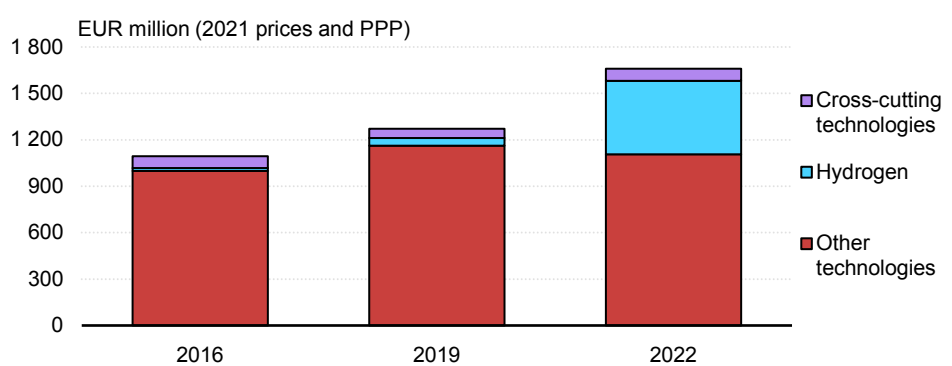
Meanwhile, a cornerstone of domestic hydrogen production will be the availability of renewable electricity. Toward this end, the government put renewed focus on the framework for renewable electricity generation through 2022 updates to the EEG and intends to follow up with additional measures to streamline and expedite permitting processes for both generation and grid infrastructure (see Focus Area 1).

Hydrogen market development will need to closely align with the electricity system. The National Hydrogen Strategy highlights the need for siting electrolyser capacity where it serves the complementary needs of the electricity system to enable hydrogen to play a key role in balancing a renewables-based power grid. While most surplus renewable electricity is generated in northern Germany, however, the bulk of hydrogen demand will be concentrated in industrial hubs in the south, possibly creating a mismatch between supply and demand for hydrogen (as already exists for electricity). Pipelines to move hydrogen from the north to the south may be no easier to site than those for electricity, which have been riddled with setbacks, delays and cost overruns.

Research, innovation and skills

The National Hydrogen Strategy notes the role that research, education and innovation will play in developing a hydrogen sector. More recently, the National Hydrogen Strategy Update also included a focus on research, innovation and skills. In particular, it calls for close co-ordination in the development of policies on research, energy, industrial, transport and environmental policies. The Strategy commits to continuing and expanding research efforts on hydrogen production, storage, transport and use in industrial applications and infrastructure, including applied energy research and energy transition living labs. Among these, its notes key initiatives such as H2Giga for hydrogen production, H2Mare for offshore hydrogen development, and TransHyDe for hydrogen transport and infrastructure, as well as funding for research and development in the transport sector under the National Innovation Programme for Hydrogen and Fuel Cell Technology, the "HyLand – Hydrogen Regions in Germany" programme, the Hydrogen Innovation and Technology Centre (ITZ), and the PtL development platform. The plan emphasises the need to provide sustained support for basic and applied research to accelerate the transition from research to production phases for technologies to ensure German competitiveness internationally (under the "Made in Germany" banner). A planned hydrogen technology and innovation roadmap is meant to tie all innovation resources together under an umbrella strategy. Germany also plans to continue international co-operation on hydrogen technologies, within the European Union and beyond.

Energy-related research, design and development investment in Germany, 2016-2022



Note: PPP = purchasing power parity.
Source: IEA (2024), Energy Technology RD&D Budgets.

The government is also planning to issue a strategy to plan for requisite skills for the hydrogen buildout. The package will include measures to promote more STEM professionals along with short-term retraining efforts for workers and medium-term programmes to increase university funding and promote the immigration of skilled workers (especially young professionals). Germany also plans to support capacity-building efforts to boost education and skills development outside of Germany, notably in sub-Saharan Africa.

Recommendations

10. Focus efforts to stimulate targeted, low-emissions hydrogen demand.

Germany's updated Hydrogen Strategy takes a comprehensive approach to fostering the development of a hydrogen economy, and the H2Global mechanism and amortisation account to finance the Hydrogen Core Network are innovative frameworks. However, final investment decisions by potential end users are lagging due to concerns about sufficient supply at affordable prices. At the same time, domestic production projects are failing to materialise as they lack strong commitment from offtakers. Additional measures are needed to jump-start investments in the market ramp-up phase, notably in the area of demand creation.

Germany is right to focus its efforts at hydrogen demand creation on industry, where some sectors have few decarbonisation alternatives. The government should closely co-ordinate with the country's industry sector to align strategies and policies with industry expectations and plans for sectoral decarbonisation. Germany can build upon successful existing programmes. Importantly and uniquely, Germany's Carbon Contracts for Difference cover not only capital expenditures but also operating expenditures, which has been key to the programme's successful uptake and deployment. Germany should move forward with a hydrogen-specific carbon contract for difference and consider allocating additional funding toward it.

The public sector could play an important role in supporting hydrogen demand by introducing "lead markets" for climate-friendly basic materials, establishing definitions, aligning on standards and criteria for materials produced with renewable or low-emissions hydrogen. Public procurement tied to this could create dedicated demand for products such as climate-friendly ("green") or low-emissions steel and cement in the early years of market development, when broader demand is limited,

notably through large infrastructure spending from state entities (e.g. rail infrastructure). The final price impact on some end-use products that use green materials – such as cars using green steel – is limited, so standards and targeted fiscal measures could promote more private demand too.

Germany should, in its strategies and communication to the public, maintain a clear focus on the use of hydrogen over time, where no suitable alternatives exist, as it will likely remain a scarce resource. In addition to its use in certain industrial sectors, hydrogen can provide seasonal storage and much needed flexibility in Germany's future electricity system. At a later stage, hydrogen derivatives will play an important role as maritime and aviation fuels. The IEA is, however, less convinced of a significant role for hydrogen in Germany's wider transport sector, and even less in space heating.

Annexes

Acknowledgements

The IEA review team visited Berlin on 25-29 November 2024 and met with government officials and public and private sector stakeholders across the energy sector. This report is based on information from these meetings, the review team's assessment of Germany's energy policy and detailed research by the IEA. The review team members were Wieger Wiersema (the Netherlands, team leader); Peter Deleu (Belgium); Samantha Kagan (United Kingdom); Cecilia Kellberg (Sweden); Philip Newsome (Ireland); Ana Maria Sanchez Infante (European Commission); and Paolo Frankl, Divya Reddy and Oskar Kvarnström from the IEA.

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Abbreviations and acronyms

BMBF	Federal Ministry of Education and Research
BMWK	Federal Ministry for Economic Affairs and Climate Action
BNetzA	Federal Network Agency
CCS	carbon capture and storage
CCUS	carbon capture, utilisation and storage
CHP	combined heat and power
CO_2	carbon dioxide
DSM	demand-side management
DSO	distribution system operator
EED	Energy Efficiency Directive
EEG	Renewable Energy Sources Act
ESR	Effort Sharing Regulation
ETS	Emissions Trading System
EU	European Union
EUR	euro
EV	electric vehicle
GHG	greenhouse gas
IEA	International Energy Agency
IPCEI	Important Projects of Common European Interest
KTF	Climate and Transformation Fund
LNG	liquefied natural gas
PtL	power-to-liquid
PV	photovoltaics
RED II	EU Renewable Energy Directive
RFNBO	renewable fuel of non-biological origin
STEM	science, technology, engineering and mathematics
TSO	transmission system operator

Units of measurement

bcm	billion cubic metres
EJ	exajoule
g CO_2/km	gramme of carbon dioxide per kilometre
GW	gigawatt
GWh	gigawatt hour
kb/d	thousand barrels per day
km	kilometre
kW	kilowatt
kWh	kilowatt hour

Mt	million tonnes
Mt CO_2-eq	million tonnes carbon dioxide equivalent
MWh	megawatt hour
PJ	petajoule
TWh	terawatt hour

See the IEA glossary for a further explanation of many of the terms used in this report.

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Energy Policy Review

Government action plays a pivotal role in ensuring secure and sustainable energy transitions and combatting the climate crisis. Energy policy is critical not just for the energy sector but also for meeting environmental, economic and social goals. Governments need to respond to their country's specific needs, adapt to regional contexts and help address global challenges. In this context, the International Energy Agency (IEA) conducts Energy Policy Reviews to support governments in developing more impactful energy and climate policies.

This *Energy Policy Review* was prepared in partnership between the Government of Germany and the IEA. It draws on the IEA's extensive knowledge and the inputs of expert peers from IEA Member countries to assess Germany's most pressing energy sector challenges and provide recommendations on how to address them, backed by international best practices. The report also highlights areas where Germany's leadership can serve as an example in promoting secure clean energy transitions. It also promotes the exchange of best practices among countries to foster learning, build consensus and strengthen political will for a sustainable and affordable clean energy future.