Status Report

Energy transition in North Rhine-Westphalia (NRW) and Baden-Württemberg (BW)

On behalf of:

Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety

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1 Introduction

The German Energiewende represents a profound transformation of both the demand and supply sides of the national energy system, aiming to reduce greenhouse gas (GHG) emissions and achieve climate neutrality by 2045 while ensuring energy security and affordability. This transformation is primarily based on two main pillars: renewable energy and energy efficiency (Sonnenschein & Hennicke, 2015). Increasingly, sector coupling through electrification and digitalization are also being recognized as a third essential pillar.

This report examines the power system transition in two German federal states, North Rhine-Westphalia (NRW) and Baden-Württemberg (BW), in the context of national and EU policy frameworks, drawing on federal and state policy documents and statistical data. It begins with an analysis of electricity consumption and supply in both states, diving into the expansion of renewable energy and the coal phase-out . The report reviews the electrification of heating, transport, and industry, highlighting measures undertaken by the two states to support this transition. As renewable electricity shares rise and electrification accelerates, system flexibility becomes increasingly critical. Accordingly, the report examines federal and state-level policies and measures that address flexibility options, including dispatchable generation, energy storage, demand-side flexibility, and market- and tariff-based mechanisms. Developments in grid infrastructure, such as network expansion, grid development planning, and the deployment of smart grid technologies, are analysed alongside state-level initiatives. Finally, the report explores the social dimension of the transition, focusing on labour market, economic diversification, and stakeholder participation. Across all dimensions, the report identifies key challenges, which form the basis for recommendations and opportunities for mutual learning with China.

2 Setting the Scene

2.1 Energy transition in NRW and BW

BW and NRW are among Germany's most populous and economically strongest federal states (see Box 1). Their success in advancing the energy transition is therefore critical to achieving the national climate targets.

Box 1

Key geographical and economic data for NRW and BW

NRW is Germany's most populous state. Located in the country's west and sharing borders with Belgium and the Netherlands, it covers approximately 34,100 km² and is home to around 18 million inhabitants (Germany Trade and Invest, n.d.). In 2023, NRW's GDP per capita was roughly €46,200, slightly below the national average of €48,750 (NRW Global Business, n.d.).

BW is Germany's third most populous state, with around 11.25 million inhabitants (Statista, 2025). Located in the south-west, it borders France and Switzerland. Economically, BW ranks third among the Länder in GDP per employed person; in 2023, its nominal GDP per capita stood at approximately €54,339 (Statistisches Landesamt Baden-Württemberg, 2024).

NRW has historically been Germany's "coal heartland", with the Rhenish mining area once described as "Europe's biggest hole" (Ghorayshi, 2014). With approx. 44 GW of electricity generation capacity, NRW currently leads among the federal states in Germany. The region's lignite phase-out is scheduled for 2030 (Kyllmann, 2022), posing both structural and socio-economic challenges as well as opportunities for economic transition with the federal financial support for the coal regions. The state's priority is now on the development of energy efficiency, renewable energies and clean hydrogen. In addition, NRW's strong industrial base, particularly in energy-intensive industries, faces the complex task of decarbonisation while maintaining global competitiveness. The state hosts the headquarters of several major energy utilities and energy-intensive industrial firms, including RWE, E.ON, Uniper, ThyssenKrupp, Bayer, and TRIMET Aluminium.

BW has followed a different trajectory: until the national nuclear phase-out decision, it relied heavily on nuclear power and has since made the expansion of renewable energy a top policy priority, next to energy efficiency. BW is also home to major energy companies, including EnBW and MVV Energie AG. Besides, BW is widely regarded as a centre of innovation, home to major clean-tech companies, leading research institutions such as different Fraunhofer Institutes and Karlsruhe Institute of Technology, and global industrial players including Bosch, Daimler, and Heidelberg Materials. Cities such as Freiburg and Heidelberg are internationally recognised for their ambitious climate strategies and pioneering energy transition plans.

2.2 Overall policy framework and governance structure

Germany's energy policy operates within a federal framework that combines national targets with autonomy for the federal states (Münzner, 2014). While the federal government sets overarching energy and climate targets – such as emission reduction targets and the expansion of renewable energies – the individual federal states have considerable freedom in designing and implementing their own regional strategies and programs to achieve these targets (Climate Chance & adelphi, 2021). They also play a major role in promoting acceptance of the energy transition (Agentur für erneuerbare Energien, 2023). The tasks of the federal states in this area include, for example, regional planning, promoting renewable energy projects, and facilitating grid expansion in line with federal strategies (Climate Chance & adelphi, 2021).

In principle, federalism offers the potential for innovation and the development of differentiated solutions for effective climate and energy policy and can strengthen the legitimacy of political decisions. Nevertheless, there are challenges – a clear division of tasks and adequate coordination are important foundations (Schlacke et al., 2025).

Germany has fixed targets, but the federal states do not have to meet a specific share of the national target quota. Instead, the targets are distributed indirectly through coordination, joint agreements, state laws that reflect federal targets, and sector-specific binding commitments (e.g., in planning law for wind energy). Further examples are joint committees, like the Federation-Länder cooperation committee (BMWE, 2022) or the Conference of Environmental Ministers (Umweltministerkonferenz) (UMK Saarland, n.d.).

The federal climate and energy policies provide the overarching framework within which NRW and BW design and implement their climate and energy transition strategies (see major federal legislations in Box 2).

With the 2021 Climate Protection Act, NRW committed to achieving climate neutrality by 2045, in line with Germany's national target. The Act defines interim carbon emission reduction targets of 65% by 2030 and 88% by 2040 (compared with 1990 emission levels). To achieve these targets, the state government has introduced concrete strategies and programs. NRW has adopted two "Climate Protection Packages" containing measures to support companies, citizens, and municipalities in the transition to climate neutrality. Its updated Energy Supply Strategy (2021) significantly raised ambitions for renewable energy deployment. Beyond expanding renewables, NRW prioritises grid modernisation, sector coupling, and the electrification of transport, while maintaining supply security, affordability, and the international competitiveness of its industry (MWIKE - NRW, n.d.-d). The Energy and Heat Strategy of NRW is a comprehensive roadmap, containing 19 fields of action and around 100 state-level measures, aimed at transforming all sectors of the energy and heat system toward climate neutrality by 2045. A central focus is on accelerating the hydrogen ramp-up and advancing the municipal heat transition, while simultaneously doubling wind and solar capacity by 2030 (compared to 2023) to ensure a secure, affordable, and competitive energy supply (MWIKE - NRW, n.d.-c). In NRW, the Ministry for Economy, Industry, Climate Protection and Energy (MWIKE) is responsible for climate and energy legislation. NRW.Energy4Climate functions as the state's energy and climate protection agency and is a driving force behind NRW's ambition to achieve climate neutrality whilst maintaining its status as Germany's leading industrial region (NRW.Energy4Climate, n.d.-b).

The Climate Protection and Climate Change Adaptation Act (Climate Act), in force since 2013, provides the overarching framework for BW's climate policy. The state has adopted more ambitious targets than the federal government, committing to climate neutrality by 2040, five years ahead of Germany's national goal, and aiming to reduce greenhouse gas emissions by 65% by 2030. It has also set a long-term objective of covering 80% of final energy consumption with renewable sources by 2050, relative to 1990 levels (LU - BW, n.d.). Electricity is central for BW's energy transition, with the state accelerating renewable energy deployment through explicit targets for wind power and ground-mounted photovoltaic (PV) systems (UM - BW, 2025d). Smart grid expansion is a key priority, recognised as essential for delivering a sustainable, cost-effective, and secure energy supply (UM - BW, 2024b). The Ministry of the Environment, Climate and Energy is the principal actor in the state's climate and energy policy. KEA-BW, the Climate Protection and Energy Agency established in 1994, supports implementation of energy efficiency and climate protection measures across the state.

Box 2

Key federal energy legislation in Germany

Federal laws strongly influence developments within the federal states.

- Germany's Energy Industry Act (Energiewirtschaftsgesetz, EnWG), first enacted in 1935 and repeatedly revised, provides the foundation for ensuring a secure, affordable, and environmentally friendly supply of gas and electricity. Its latest amendment, adopted in February 2025, aims to reduce temporary generation surpluses and increase flexibility in grid usage.
- In 2000, the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG) replaced the 1991 Electricity Feed-In Law (Stromeinspeisungsgesetz), one of the world's first green electricity feed-in tariff schemes. It stipulates the expansion targets, the right to feed in green electricity, the auction procedures required for medium to large installations, and the remuneration for feed-in.
- In 2020 the Act to Reduce and End Coal-Fired Power Generation (Gesetz zur Reduzierung und zur Beendigung der Kohleverstromung, Kohleausstiegsgesetz) was adopted, setting a roadmap for the phase-out of coal power plants by 2038 at the latest. The law combines decommissioning schedules, compensation mechanisms for operators, and support for structural change in affected regions.
- In 2023, the Energy Efficiency Act (Energieeffizienzgesetz, EnEfG) was adopted, setting a target to reduce primary energy consumption by 39.3% compared to 2008 levels by 2030, and final energy consumption by 26.5%.

In the following chapters, these laws will be discussed in connection with the specific dimensions of the energy transition.

Alongside these acts, market-based climate policy instruments play a key role. Germany participates in the European Union Emissions Trading System (EU ETS), which covers large industrial plants and the energy sector, and since 2021 also operates a national emissions trading scheme (Brennstoffemissionshandelsgesetz) for the heating and transport sectors. In addition, energy taxation creates price incentives for more efficient and climate-friendly energy use.

* Only the most significant acts are noted here, without any claim to completeness or detailed legal interpretation. All of these laws are also based on the respective EU legislation. Some of the latest reforms in EU legislation still have to be implemented in German laws, for example, the energy efficiency first principle.

3 Energy Consumption and Supply in NRW and BW

The focus in this chapter lies on electricity consumption and supply, but within the context of total final and primary energy consumption.

3.1 Energy consumption, particularly electricity consumption by sector

In 2024, Germany's final energy consumption totalled 8,095 PJ, with the transport, households and industrial sectors representing large shares, as illustrated in Figure 1. Energy demand in transport is dominated by fuels used for cars, trucks, and buses. In industry, approximately two-thirds of total energy use is devoted to process heat. Space heating, by contrast, constitutes only a small share of industrial consumption. In the residential and commercial sectors, however, space heating accounts for around 70% of final energy use (AGEB, 2025).

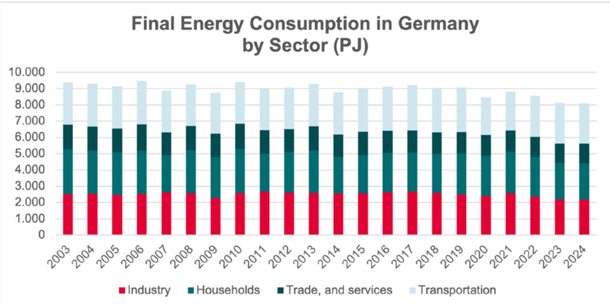


Figure 1 Final energy consumption (in PJ) in Germany. Source: (AGEB, 2025)

In 2023, Germany's electricity consumption was distributed among various sectors: 42.5% in industry, 27.9% in residential, 25.0% in Commercial and public services and 3.6% in transport. The industrial sector remains the largest consumer, reflecting Germany's strong manufacturing base (IEA, 2024).

Although energy efficiency has steadily improved and partial energy savings have been realised, these gains have been partly offset by continued economic growth and rising levels of consumption, driven for example by increases in floor area and higher service demand. As a result, the decline in absolute final energy consumption has been more limited than expected. In addition, electrification through the deployment of heat pumps, battery electric vehicles (BEVs) and electrified industrial processes could deliver greater fuel savings than the associated increase in electricity use, but progress in remains slower than required. Achieving the targets set under the Energy Efficiency Act will therefore require additional policy and investment efforts. The law mandates a 26.5% reduction in final energy consumption by 2030 compared with 2008 levels, and a 45% reduction by 2045 (UBA, 2025b).

NRW is one of Germany's most important industrial regions, characterized by a strong presence of energy-intensive raw materials industries such as steel, cement, and chemicals. The industrial sector plays a pivotal role in the region's economy and is also a major energy consumer. Remarkably, around 40% of Germany's total industrial final energy consumption takes place in NRW (LANUK - NRW, n.d.-c). The largest share of energy consumption in the industry sectors occurs within the economic activities "manufacture of basic metals" and "manufacture of chemicals and chemical products" (IT. NRW, n.d.). Total final energy consumption in NRW amounted to 2,088,073 TJ in 2021 (Germany: 8 789 397 TJ) (Statistisches Bundesamt, n.d.). Electricity consumption in NRW amounted to 123.6 TWh in 2020 (LANUK - NRW, n.d.-a).

BW: The largest share of energy consumption in the industry sector in BW occurs within the economic activities "manufacture of paper and paper products", "manufacture of non-metallic mineral products" and "manufacture of motor vehicles, trailers and semi-trailers" (IT.NRW, n.d.). Mercedes-Benz and Porsche are headquartered here, and it employs the highest number of automotive industry workers among German states; furthermore, about one-third of all machines produced in Germany originate from BW (Baden-Wuerttemberg, n.d.; IHK Nordschwarzwald, n.d.). This shows the strong concentration of energy-intensive manufacturing industries, especially the automotive sector, and the high electricity demand. Total final energy consumption in BW amounted to 1,027,592 TJ in 2021 (Germany: 8 789 397 TJ) (Statistisches Bundesamt, n.d.). Electricity consumption in BW amounted to 62.4 TWh in 2023 (Statistisches Landesamt Baden-Württemberg, 2025).

3.2 Electricity generation mix

Table 1 shows the electricity generation mix in BW and NRW. NRW's coal heritage remains clearly visible today. It holds the highest share of lignite capacity among all German states, and the second highest share of hard coal. Despite this, the installed capacity of renewable energy sources in NRW is now only slightly below that of non-renewable sources, reflecting a gradual but significant shift in the region's energy landscape (Bundesnetzagentur & Bundeskartellamt, 2025).

In terms of gross electricity generation, NRW produced a total of 107.07 TWh in 2024. Coal remained the dominant source with 41.11 TWh (47%), followed by natural gas (20.54 TWh or 23%). Renewable energy sources contributed a combined total of 23.5 TWh (27%), underlining their growing importance(Information und Technik Nordrhein-Westfalen, 2025) .

Table 1 Electricity generation mix in BW and NRW (2024)

Electicity Generation Mix	BW (in MW)	NRW (in MW)
Lignite	2	6,004
Coal	5,228	4,549
Natural Gas	2,026	10,066
Mineral Oil	957	637
Pumped hydro storage	1,899	300
Wind Onshore	1,940	8,353
Wind Offshore	0	0
Solar	12,168	11,709
Biomass	931	1,177
Hydro	1,568	184

Source: Federal Network Agency's (BNetzA) power plant database[1]
(Note: This table shows major generation sources only.)

BW has historically been a key location for nuclear energy in Germany, with five nuclear power plants operating at three sites: In line with Germany's national nuclear phase-out policy, these plants were gradually taken offline between 2005 and 2023 (UM - BW, 2025a). In terms of gross electricity generation, BW produced a total of 37.15 TWh in 2023. Lignite accounted for 25%, natural gas for 11%, and renewable energy sources accounted for 53%. Nuclear power contributed for 5% of the state's gross electricity generation. This share had dropped sharply in the last year, following the final shutdown of a nuclear plant in Germany (Kampffmeyer 2025).

3.3 Coal phase-out

The Act to Reduce and End Coal-Fired Power Generation (Gesetz zur Reduzierung und zur Beendigung der Kohleverstromung) enshrines in law the energy policy recommendations of the Commission on Growth, Structural Change and Employment (the "Coal Commission") of 2018. The Act provides for a gradual phase-out of coal-fired power generation, with full decommissioning to be completed by 2038 at the latest. However, compared to other EU countries, Germany's planned coal phase-out is considered relatively late (Beyond Fossil Fuels, n.d.). A detailed roadmap lays out the step-by-step decommissioning of coal-fired power plants in Germany.

In October 2022, the federal government, the state of NRW, and energy utility RWE concluded a landmark agreement to advance the lignite phase-out in NRW to 2030, eight years ahead of the federal schedule (Die Bundesregierung, 2022; MWIKE - NRW, n.d.-a). This accelerated timeline requires significant adjustments to lignite mining operations, particularly in the Rhineland opencast mines. Planned mine extensions have been cancelled, and several areas previously designated for extraction, including villages once slated for resettlement, will now be preserved. To ensure a just transition, targeted structural programs and investments are being deployed to support workers and communities in the Rhenish mining region. These measures focus on fostering innovation, developing green industries, and upgrading regional infrastructure to create sustainable economic opportunities (Chapter 7).

1 https://www.bundesnetzagentur.de/DE/Fachthemen/ElektrizitaetundGas/Versorgungssicherheit/Erzeugungskapazitaeten/Kraftwerksliste/start.html

Although BW is not a traditional coal-mining region, it has actively supported Germany's national coal phase-out by planning to retire its limited number of hard coal power plants, with the aim of completing the phase-out ideally by 2030 (UM - BW, 2021). In line with this target, EnBW, the state's largest hard coal power plant operator, has committed to achieving climate-neutral electricity and heat production during the 2030s (EnBW, n.d.). In spring 2025, EnBW converted its Stuttgart-Münster power plant from coal to a hydrogen-ready gas turbine facility, with plans to complete a full conversion to 100% hydrogen operation by mid-2030 (Bisch, 2025).

3.4 Renewable energy expansion

Achieving climate neutrality by 2045 will require a substantial expansion of renewable energy, complemented by measures to improve energy efficiency. Developments in federal states such as NRW and BW are shaped by decisions at the federal and European Union levels, while the states themselves play a key role in implementing these policies on the ground.

At the federal level, the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG) sets the target of increasing the share of renewables in Germany's gross electricity consumption to 80% by 2030. To achieve this objective, technology-specific installation targets have been defined for key renewable energy sources:

- Onshore wind energy: approximately 115 GW installed capacity by 2030;
- Offshore wind energy: approximately 30 GW installed capacity by 2030;
- PV: approximately 215 GW installed capacity by 2030.

The installed capacity of renewable energies for electricity generation in NRW was around 19.7 GW at the end of June 2024 (MWIKE - NRW, n.d.-e). NRW currently has about 7.4 GW of installed capacity (wind energy), around 12% of Germany's total. The state supports federal efforts to accelerate expansion and aims to add at least 1,000 new turbines by 2027 (expansion to 27 GW). With over 10 GW installed, NRW holds about 12% of national solar capacity (MWIKE - NRW, n.d.-c).

BW has set the goal of becoming climate neutral by 2040. Under its 2024 energy strategy, the state aims to generate around 80% of its gross electricity from renewable sources by 2030, rising to almost 100% by 2040. The strategy relies primarily on expanding PV and wind capacity. For wind energy, annual capacity additions are planned to rise linearly to 700 MW by 2027 and remain at this level through 2040. For PV, the state aims for approximately 24.6 GW of installed capacity by 2030, driven in part by mandatory PV installation on new buildings and roof renovations (UM - BW, n.d.).

Figure 2 illustrates the current status of the installed gross capacity of different renewable energies in the two states.

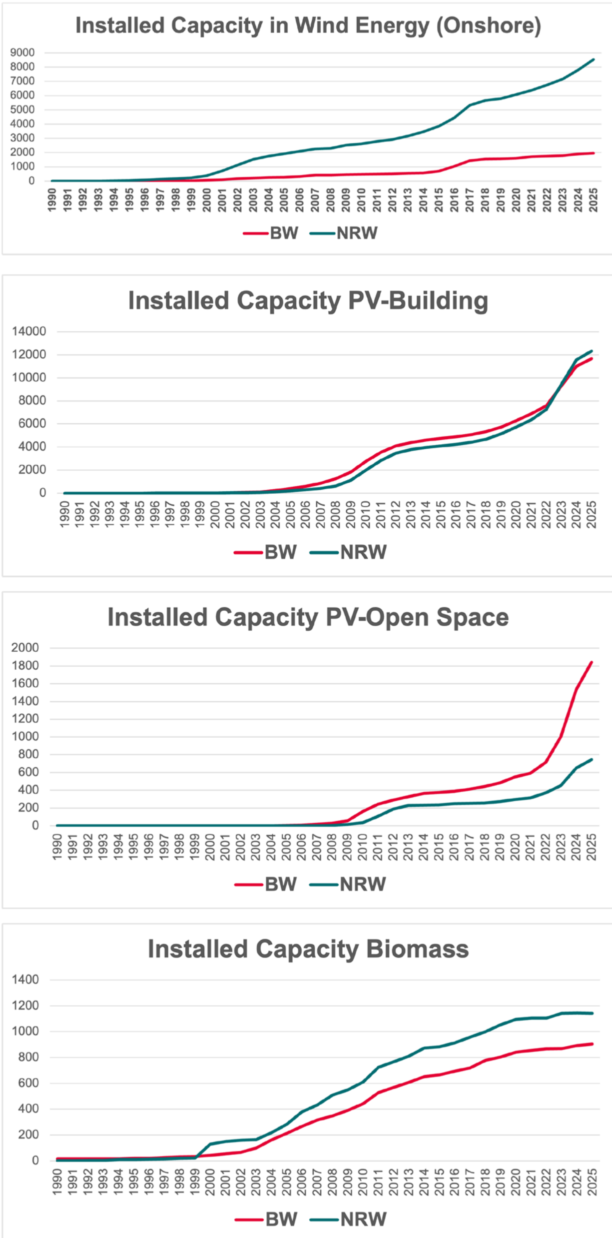


Figure 2 Installed capacity of renewable energies in NRW and BW

4 Renewable Energy-Based Electrification

4.1 Status, progress and future trends

Meeting Germany's target of GHG neutrality by 2045 requires deep electrification of buildings, industry, and transport, underpinned by a rapid and affordable expansion of renewable electricity supply (Section 3.4). Scenario analysis for Germany's climate-neutral transition suggests the following emergent trends (BMWE, 2024a; Luderer et al., 2025):

- Transport: The long-term pathway converges on full deployment of BEVs for passenger cars, with heavy trucks and buses largely electrified where feasible. Green hydrogen and derivative fuels are reserved for aviation, shipping, and long-haul transport.
- Buildings: Heat pumps would deliver space and water heating in roughly two-thirds of the building stock. About 30% of buildings may rely on district heating systems using renewable electricity or low-carbon fuels, with sustainable biomass covering residual demand.
- Industry: A diversified electrification mix is likely, combining direct electrification of process heat and green hydrogen. The exact technology shares remain highly dependent on cost trajectories and infrastructure deployment.

Direct electrification provides the highest energy conversion efficiency and lowest mitigation costs across end-use sectors. When accompanied by improvements in building efficiency and the adoption of a more resource-efficient, circular industrial economy, total final energy demand is projected to fall by around 32–38% by 2045 relative to 2023 levels.

Figure 3 illustrates the current progress of the transition to renewable energy sources in Germany's electricity sector, where renewables now account for more than half of total electricity generation. Germany's heat pump market has expanded rapidly over the past few years. The installed stock reached 1.674 million units by 2022

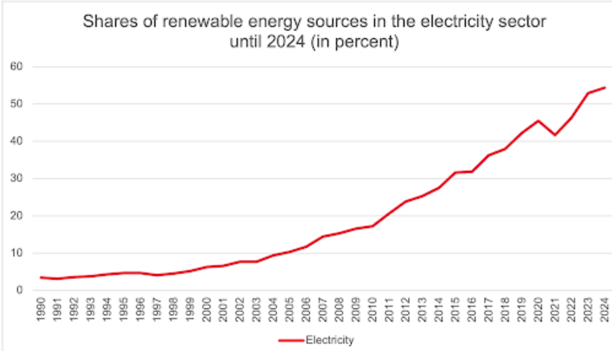


Figure 3 Share of renewable energy sources in the electricity sector until 2024
Source: (UBA, 2025a)

(European Commission, 2024), rising sharply with record sales of 356,000 units in 2023 (Hannen, 2024). However, installations dipped to around 193,000 in 2024, a drop of almost 46%, reflecting policy uncertainty and changing subsidy structures (Pion, 2025). Despite the recent slowdown, heat pumps now play a crucial role in Germany's heating transition, representing a steadily growing share of residential heating systems (KfW, 2025). Germany is Europe's largest automotive market. With a registered fleet of roughly 1.65 million BEVs at the start of 2025 – about 3.3% of the total passenger car stock – Germany has still a long way to go to achieve its self-imposed target of 15 million BEVs (Wettengel, 2025). BEV sales accounted for around 13.5% of new registrations in 2024 (European Commission, 2025). The growth slowed after the reduction of purchase subsidies (Wettengel, 2025). To address this situation, the German government reached a new subsidy plan for private purchases of BEV at the beginning of 2026, which intends to invest 3 billion Euros in 2026-28 to revive financial incentives for purchasing BEV. On the other hand, the current discussions about weakening the EU ban on combustion engines do not serve to strengthen the BEV market (Dahl & Hülsemann, 2025).

Based on the Climate Protection Act of 2021 and with its "Energy and Heat Strategy", NRW is systematically advancing electrification as a core strategy to reduce emissions. This includes measures in the transport, building and industry sector.

The final energy consumption in NRW's transport sector was 463,228 TJ in 2022, out of which BEVs accounted for 8,682 TJ, representing less than 2% of the total (LANUK - NRW, n.d.-b). Nevertheless, between 2017 and November 2024, the number of purely battery-powered cars had increased from just 9,000 to around 364,000, reaching 412,000 by August 2025 (MWIKE - NRW, n.d.-b)“container-title”:“Wirtschaft.NRW”,“genre”:“Ministerium für Wirtschaft, Industrie, Klimaschutz und Energie des Landes Nordrhein-Westfalen”,“language”:“de”,“title”:“Emissionsarme Mobilität”,“URL”:“https://www.wirtschaft.nrw/emissionsarme-mobilitaet”,“author”:[{“literal”:“MWIKE - NRW”}],“accessed”:{“date-parts”:[[“2025”,9,26]]}}],“schema”:“https://github.com/citation-style-language/schema/raw/master/csl-citation.json”} . Progress is also evident in freight transport. With about 5,800 heavy electric trucks, NRW currently leads all German Länder. Public charging infrastructure has expanded rapidly: since January 2023, the number of public charging points has more than doubled to over 33,200. This development has been supported by targeted public funding, research and development initiatives, and the strategic expansion of the charging network (MWIKE - NRW, 2025c).

To further advance transport electrification, NRW is prioritising the continued expansion of charging infrastructure and grid development (Chapter 6). In addition, NRW's Action Plan for Heavy Road Freight Transport (MWIKE - NRW, 2022) promotes the deployment of zero-emission vehicle technologies through information campaigns, workshops, pilot projects, and dedicated infrastructure support. Initiatives such as HyTrucks. NRW identify network needs, assist operators, and facilitate cost-efficient procurement.

In the buildings sector, NRW promotes electrification primarily through the deployment of heat pumps and other innovative energy technologies (Airwende, n.d.). In 2022, total energy input for heat generation in NRW amounted to 150,542 TJ, of which renewable fuels contributed 18,575 TJ (12%), while electricity accounted for 12,771 TJ (8%) (MWIKE - NRW, 2025c). At the household level, individuals can access national support schemes, such as KfW's heating subsidies, which provide financial assistance for the installation of efficient heating systems or connections to building and district heating networks (KfW, n.d.).

In the industrial sector, NRW promotes the modernisation of industrial processes through collaborative projects between business, research institutions, and academia. These initiatives focus on GHG–neutral technologies, efficient and flexible energy use, and climate-neutral production processes (MWIKE - NRW, n.d.-e).

In the Energy and Heat Strategy of North Rhine-Westphalia, measures are listed to make the energy supply climate-neutral, affordable and secure. Recognising that electricity prices are a decisive factor for industrial electrification, NRW consistently advocates at the federal level for electricity price relief. Proposed measures include predictable electricity price reductions for energy-intensive industries (which are particularly needed during the transformation phase), the stabilisation of the federal subsidy for transmission grid charges, a long-term reduction in electricity tax for all companies (but also households), new business models for load flexibility and “use instead of curtailment” approaches, and greater direct access to renewable electricity through power purchase agreements (PPAs) and direct supply.

As in NRW, **BW** pursues electrification strategies across the buildings, transport, and industry sectors. The state seeks to position itself as a pioneer in electric mobility, backed by targeted subsidy programmes and the expansion of charging infrastructure. Its goal is for every second car to be climate-neutral by 2030, with a strong emphasis on BEVs. The Ministry of Transport outlines several measures to accelerate the uptake of BEVs (VM - BW, n.d.):

- Expanding and securing charging infrastructure for both public and private use, particularly for passenger vehicles.
- Stimulating market penetration through the targeted electrification of commercial fleets by 2027, supported by regulatory and financial incentives such as revised company-car taxation and fleet quotas.
- Prioritising climate-friendly vehicles via enhanced implementation of the Electric Mobility Act (EmoG), including preferential parking, access to bus lanes, and exemptions from traffic restrictions.

In the buildings sector, BW focuses on building modernisation and the expansion of heat pump deployment. As a front-runner state, BW has adopted binding local heat planning measures in accordance with the Federal Climate Action Act, making municipal heat planning mandatory across all municipalities. The corresponding legislation (§ 27 KlimaG BW) serves as a model for similar laws in other German states (Energy Cities, 2024). BW introduced the Renewable Energies Heat Act in 2015, requiring that at least 15% of the energy used in newly installed heating systems originate from renewable sources (UM - BW, 2024a).

In the industrial sector, the state government is pursuing the development of a competitive BEV ecosystem, recognising it as essential for maintaining the region's industrial base while strengthening innovation capacity and long-term competitiveness (Electric Mobility South-West, n.d.) .

4.2 Key challenges for electrification

Deep electrification across all end-use sectors faces a range of structural, technical and economic challenges:

- Rising electricity demand. As electric mobility, heat pump deployment, electrification of industrial processes, and electrolysis for hydrogen production accelerate, Germany's electricity demand is projected to increase from around 525 TWh in 2023 to potentially up to 750 TWh by 2030 (BMWE, 2025b)[2], and to 1,000 TWh or more by 2045. Meeting this growth will require a rapid and sustained expansion of renewable power generation capacity and parallel investment in transmission and distribution networks.

- Grid adaptation and flexibility. The combination of massive, variable new electricity loads from electrification and the structural shift away from synchronous, centralised power generation creates significant challenges for grid stability and flexibility (Bundesnetzagentur, 2025a). This underscores the need to accelerate grid reinforcement, particularly at the distribution level, supported by smart grid solutions (Section 6.3) and the mobilisation of new electrical loads themselves as active sources of flexibility (Section 5.3). In addition, the integration of storage systems into the network – especially in light of potential grid load – is another challenge.

2 However, recent studies predict a lower range of 600–700 TWh in 2030 (see monitoring report from September 2025) (EWI & BET Consulting GmbH, 2025).

- A transition period with high electricity prices. The most pressing macro- and microeconomic challenge to electrification in Germany is the high cost of electricity compared to fossil fuels. While the expansion of cheap renewable energies is expected to reduce wholesale power prices in the future, the temporary high need for investment in transmission and distribution networks as well as flexibility options is currently driving power prices up. As soon as demand increases through electrification, these costs will be spread over more kWh, leading to lower prices again.

Besides these cross-sectoral challenges, each end-use sector also faces specific barriers to electrification, including:

- Transport: Charging point rollout uneven & grid-dependent. Public charging density is markedly higher in cities than in rural areas; NRW's municipal map shows large regional gaps despite rapid growth (Bundesnetzagentur, 2025a).

- Buildings: Slow renovation and boiler turnover. Deep energy retrofits and replacement rate of fossil-fuel boilers lag and the Gebäudeenergiegesetz (GEG) debate about boiler replacement created uncertainty and delayed decisions by households and building owners (Haas et al., 2025) there has been a certain reorientation in the field of transition studies. For a long time, the concept of ecological modernization and the focus on green niches were predominant. However, in light of the overall slow pace of sustainability transitions and increasing conflicts surrounding environmental and climate policy measures, there has been a stronger focus on incumbent and right-wing populist actors. The intense debates surrounding the so-called heating law (Gebäudeenergiegesetz, GEG).

- Industry: Commercially available industrial heat pumps are increasingly capable of generating process steam, but their use at higher temperature levels (above about 160°C) and under elevated steam pressures still requires further technical development and scale-up (Fleiter et al., 2024).
  In addition, electricity prices for industrial consumers remain 1.5 to 2.5 times higher than those faced by major international competitors. These elevated costs undermine industrial competitiveness, weaken incentives for electrification (BDI, 2025; DIHK, 2024).

5 System Flexibility

As outlined in previous chapters, Germany's electricity system is undergoing rapid transformation: coal is being phased out, large volumes of variable renewable generation from wind an PV energy are being integrated, and electrification of transport, heating, and industry is accelerating. Enhancing system flexibility is therefore essential to maintain operational efficiency, ensure secure supply, and enable the cost-effective integration of renewables.

This chapter examines four key forms of system flexibility: dispatchable generation capacity, energy storage, demand-side flexibility, and market- and tariff-based mechanisms. It reviews the main federal and state-level policies aimed at unlocking these flexibility options and analyses the remaining challenges to their effective implementation.

Although the chapter starts with dispatchable generation capacity, as it remains an essential component of system flexibility, the need for new or replacement plants of this type can be reduced by drawing on alternative sources. Recent EU legislation, notably the Energy Efficiency Directive (Articles 3 and 27), mandates a systematic approach to planning and policy-making guided by the principle of "energy efficiency first." In practice, this requires that energy storage, other demand-side flexibility, and market- or tariff-based mechanisms (Section 5.2, 5.3,5.4) be prioritised over additional dispatchable generation wherever they can provide an equivalent level of reliability at lower cost.

5.1 Dispatchable generation capacity

To address the need for flexible power generation, gas-fired power plants are the conventional option in Germany, due to the decision to phase out coal. At the federal level, the government's coalition agreement (2025) originally set a target of up to 20 GW of gas-fired power plant capacity by 2030. Under the previous government, a key element of this strategy was the rapid or mid-term transition toward hydrogen. The proposed legislation of the previous government, then called Kraftwerkssicherheitsgesetz (Law to secure power plant capacities, KWSG) (2024) outlined a staged approach for new construction and retrofitting, but never went into force[3]:

- Pillar 1: The development of 7.5 GW of hydrogen-ready capacity, comprising 5 GW of new hydrogen-ready plants and 2 GW of retrofitted plants, to be converted to actually using hydrogen by the mid-2030ies, and 0.5 GW of newly build H2-sprinter power plants.
- Pillar 2: The construction of 5 GW of new natural gas power plants.

Based on EU the legislative framework on power markets and subsidies, the European Commission (EC) approved calls for tenders for only this part of Germany's planned new dispatchable capacity.

With the new government, the plan has since been revised after another round of discussion with the European Commission. As of mid November 2025, the government coalition agreed on a new power plant strategy but revised it again in January 2026. It now plans to tender 10 GW of natural gas-fired power plants in 2026 to be built by 2030, with a requirement for hydrogen-readiness but no requirement for when to actually use hydrogen[4]. For the actual transition to hydrogen, 2 GW shall receive incentives through contracts for difference to convert in 2040, and another 2 GW from 2043. The respective auctions would be held in 2027 and 2029, respectively. This would not create new capacities. Another 2 GW shall be auctioned in 2026 for partly technology-open controllable capacities (e.g., batteries, but current plans exclude demand response)[5].

3 In addition, the plan included 0.5 GW of grid-scale batteries.

4 https://background.tagesspiegel.de/energie-und-klima/briefing/koalition-schreibt-acht-gigawatt-gaskraftwerke-aus; https://background.tagesspiegel.de/energie-und-klima/briefing/bundesregierung-aendert-kraftwerksplaene

5 https://www.duh.de/presse/pressemitteilungen/pressemitteilung/deutsche-umwelthilfe-zur-einigung-ueber-neue-gaskraftwerke-schlappe-fuer-katherina-reiche-aber-kein/

These plans are leaving a shortfall of around 7.5 GW from the government's 20 GW target that has yet to be addressed. A long-term capacity market mechanism intended to stimulate investment in these plants remains under development and has not yet been finalised (BMWE, 2024b). In addition, the latest Action Plan, published in mid-September 2025 in response to the so-called Energy Transition Monitoring Report of the new government, emphasises the need to establish a technology-neutral capacity market as quickly as possible, ideally by 2027 (Section 5.4). These plans are still valid as of January 2026.

As a new policy focus, the BMWE also aims to strengthen the role of carbon capture, utilisation/storage (CCS/CCU) by integrating it into a technology-neutral regulatory framework. Whereas hydrogen readiness is identified as a specific requirement for new backup capacity, CCS/CCU is presented as a broader strategic technology that is essential for the decarbonisation of energy-intensive industries such as cement and chemicals, but there still is debate as to whether it should be a complementary measure for reducing residual emissions from the power sector.

In addition, bioenergy was recognised as an important source of flexible generation and highlighted as a key complement to the previously planned federal Kraftwerkssicherheitsgesetz (KWSG, 2024) owing to its dispatchable characteristics and contribution to system stability. The new government coalition has yet to address the role of bioenergy in the future power system. The Renewable Energy Sources Act (EEG, 2023) sets a target of 8.4 GW of installed biomass capacity by 2030, while the federal coalition agreement underscores the need to fully exploit the flexibility potential of biomass plants. Recent analyses indicate that, under more flexible operation, the technical potential of bioenergy generation could be tripled through use of biogas and heat storage, enabling it to make a more substantial contribution to system stability.

As Germany's largest industrial state, NRW has taken a proactive role in developing new dispatchable capacity. The state's Energie- und Wärmestrategie (2024) sets a target of approximately 5 GW of hydrogen-capable gas-fired power plants by 2030, fully aligned with federal objectives. Operators have already announced projects totalling around 5 GW, including hydrogen-ready facilities[6], though final investment decisions are still pending. According to the Federal Network Agency's (BNetzA) power plant database[7], NRW has a total installed generation capacity of 46 GW,, of which 10 GW is natural gas-based, including 8.8 GW currently in active operation. Within this portfolio, 966 MW is designated as capacity reserve and 633 MW is temporarily out of service but could be reactivated in periods of shortage. The NRW strategy also stresses the system-friendly and flexible operation of bioenergy and hydropower. NRW aims to maintain and optimise its existing bioenergy capacity, expanding it from 1.3 GW today to between 1.5 and 1.8 GW by 2030.

In BW, the state strategy similarly prioritises hydrogen and system flexibility. The Energiekonzept Baden-Württemberg identifies a need for at least 5 GW of dispatchable capacity by 2030, with a complete transition to climate-neutral energy sources, such as hydrogen, by 2040 at the latest. A concrete step toward this goal was achieved in April 2025, with the commissioning of one of Germany's first hydrogen-ready combined heat and power (CHP) plants in Stuttgart, capable of delivering 124 MW of electricity and 370 MW of thermal energy. Furthermore, the Biogas-Strategie BW (2023) sets out measures to enhance system-friendly and flexible biogas production to support grid stability. According to the BNetzA database[8], BW has a total generation capacity of 27 GW, of which 2 GW is natural gas-fired, including 1.7 GW in active operation. Within this capacity, 363 MW is held in grid reserve, 4 MW is temporarily out of service.

5.2 Energy storage

Energy storage is set to become a cornerstone of Germany's future electricity system. The 2025 federal coalition agreement prioritises the accelerated deployment of system-friendly storage and bidirectional charging for BEVs as key technologies for increasing grid flexibility. The federal strategy focuses on improving the regulatory

6 In Weisweiler and Werne

7 https://www.bundesnetzagentur.de/DE/Fachthemen/ElektrizitaetundGas/Versorgungssicherheit/Erzeugungskapazitaeten/Kraftwerksliste/start.html

8 https://www.bundesnetzagentur.de/DE/Fachthemen/ElektrizitaetundGas/Versorgungssicherheit/Erzeugungskapazitaeten/Kraftwerksliste/start.html

framework to facilitate investment and deployment. Among the measures under consideration are on one side the extension of grid-fee exemptions for large batteries beyond their current legal end date in 2029, but on the other side also the implementation of special storage grid fees, dynamic grid fees and grid fees for power producers (which would also relate to renewable energies)[9]. For the use of BEVs in V2G schemes and for the use of home and industrial storage systems to feed back into the grid, grid fees have recently been abolished in the EnWG (see below), and the regulation for V2G may soon make its application easier. In parallel, the government aims to expand the use of pumped hydro storage as a proven large-scale balancing technology, although the potential for new installations remains limited. Together, these technologies represent an integrated approach that combines both stationary and mobile storage solutions to support system stability.

Federal legislation governing energy storage includes the Energy Industry Act (EnWG), the Renewable Energy Sources Act (EEG), and the Act on the Digitisation of the Energy Transition (GDEW). The EnWG defines the legal status of storage facilities and, through recent amendments, eliminated the double charging of grid fees for electricity stored and subsequently fed back into the grid from BEVs and home/industrial batteries, as mentioned above. The GDEW mandates the nationwide rollout of smart meters, enabling dynamic tariffs that allow storage systems to charge when electricity is abundant and inexpensive, and discharge during peak demand. These reforms enhance both grid stability and the economic case for storage deployment. Complementing these measures, the federal government adopted the Electricity Storage Strategy (BMWE, 2023), which sets out concrete actions to promote the sustained expansion and integration of electricity storage across all levels of the energy system.

NRW has adopted a proactive approach with its Action Plan Energy Storage NRW (MWIKE - NRW, 2024b), which promotes a technology-neutral expansion of storage and calls for the explicit recognition of storage systems as providers of flexibility within regulatory and planning frameworks. The plan seeks to accelerate deployment by simplifying planning, permitting, and approval processes. A central element is the rapid rollout of bidirectional charging, enabling BEVs to operate as mobile storage units that contribute to grid stability.

The state's Charging Infrastructure Action Plan (MWIKE - NRW, 2023) highlights bidirectional charging as a crucial tool for improving grid stability and commits to developing the necessary technical and regulatory frameworks for large-scale application. Pilot projects and stakeholders should be supported through EU and state-level subsidies, while NRW also works to create reliable investment conditions by reducing regulatory uncertainty and advocating for coherent federal framework conditions.

As of December 2024, NRW had an installed battery storage capacity of 3,230 MWh (Bundesnetzagentur & RWTH Aachen, 2024). RWE completed one of Germany's largest battery energy storage systems at its Neurath and Hamm power plant sites in NRW. The system provides 220 MW of power output and 235 MWh of storage capacity, available for grid balancing within seconds (RWE, 2025).

BW likewise places strong emphasis on energy storage as part of its broader flexibility strategy. The state's energy policy explicitly promotes bidirectional charging to support grid stability. BW's energy concept adopts a holistic perspective, recognising not only the importance of electrical storage but also the potential of thermal storage as a key flexibility option, as the electricity and heating sectors become increasingly integrated in a decarbonised energy system.

BW is Germany's leading hub for battery research and innovation, and the Innovation and Future Agenda Baden-Württemberg (2025) sets out a strategic focus on research, development, and industrialisation of next-generation technologies, including batteries, fuel cells, and electrolysers (BW, 2025b). As of December 2024, BW had an installed battery storage capacity of 2,560 MWh (Bundesnetzagentur & RWTH Aachen, 2024).

The state's largest projects are led by the energy provider EnBW. At the Philippsburg site of a former nuclear power plant, the company is planning one of Germany's largest battery storage facilities, with 400 MW of output and 800 MWh of storage capacity, scheduled for commissioning in 2027. At Marbach, EnBW is constructing another

9 https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2025/20250512_AgNes.html

facility with 100 MW of output and 100 MWh of capacity, expected to be commissioned later in 2025 (EnBW, 2024).

5.3 Demand side flexibility beyond battery storage

Demand-side flexibility (DSF) has emerged as a central strategy for balancing the power system by adjusting electricity consumption in response to supply conditions. Once a niche service, DSF is now becoming a core component of Germany's future energy system, driven by the proliferation of new technologies and supportive federal and state-level policy frameworks.

Historically, dispatchable consumer loads particularly in industry have played a role in providing ancillary services, such as control power, to ensure grid stability. Federal policy now aims to expand DSF participation across all sectors, integrating new flexible loads such as BEVs, heat pumps, and electrolysers into grid operation. Numerous studies confirm that these emerging loads represent a major source of latent flexibility, capable of reducing system costs and supporting the integration of variable renewables. The federal strategy thus moves beyond traditional industrial applications toward a broader mix of consumer and industrial resources.

The legal basis for DSF rests on three key acts:

- the Electricity Market Act (2016), which introduced the concept of an "electricity market 2.0" based on competition between all forms of flexibility, including generation, storage, and demand-side response, so that transparent price signals drive system balancing;
- the EnWG, which provides the overarching regulatory framework for the energy sector and, through recent amendments, defines "controllable consumption devices" (e.g. heat pumps, BEV chargers) that grid operators can temporarily control or limit to avoid network overloads and ensure secure system operation;
- the GDEW, which mandates the national smart meter rollout and introduces dynamic tariffs, both essential for enabling automated DSF, particularly in the household sector.

NRW is developing a Load Flexibility Action Plan to systematically tap into a wide range of flexible resources. The plan will target both aggregated small-scale flexibilities in households and neighbourhoods, such as through residential batteries and large-scale industrial flexibility in trade and manufacturing. This dual focus reflects NRW's unique energy profile, which combines a strong industrial base with significant established flexibility potential and an increasing share of distributed renewable generation that can be aggregated to provide system services.

A leading example is TRIMET Aluminium, which has modified its production processes at its Essen facility to provide substantial flexibility. Since 2019, the company has been able to vary its electricity consumption by up to 25% for periods of up to two days, creating a flexibility buffer equivalent to around 1 GWh of storage capacity (NRW.Energy4Climate, n.d.-a; Wuppertal Institut, n.d.).

In BW, DSF is a core pillar of the state's energy concept and is closely linked to its digitalisation strategy for the energy industry. BW views the digital transformation of the grid as the prerequisite for scaling up DSF, enabling consumers, from households to major industrial facilities, to respond dynamically to price signals and real-time grid conditions (Chapter 6).

Research institutions play a key role in operationalising DSF. The Karlsruhe Institute of Technology (KIT) runs several living lab projects testing coordinated control of BEVs and heat pumps, as well as aggregation of residential battery storage (Spatafora, n.d.). The DSM Baden-Württemberg pilot project, supported by DENA, helps companies identify and monetise their flexibility potential. Stuttgart Airport was the first participant to successfully commercialise its flexible loads, generating direct revenue from demand-side management (Dena, 2016).

5.4 Market and tariff-based flexibility

This category of flexibility refers to market mechanisms and electricity tariffs that incentivise the use of flexibility. These options are designed at the national and broader European level, which shape flexibility potentials and use in the two states. Here we highlight a few key components and recent developments.

Spot Market

In Europe, electricity generation and supply, namely the sale of electricity to final customers, are unbundled from the operation of transmission and distribution networks. While the grid remains a regulated monopoly, power generation and retail supply operate under full market competition. Electricity is traded in an energy-only market (EOM), where transactions occur either over the counter (OTC) or through exchange-based platforms within the wholesale market. The wholesale market is divided into two main segments: the spot market and the futures market. In Germany, the spot market is primarily operated by EPEX SPOT and covers electricity deliveries for the following day (day-ahead) as well as the current day (intraday).

Market coupling, which links national bidding zones across EU Member States, plays a central role in ensuring that electricity prices reflect both cross-border transmission capacity and the broader pan-European supply–demand balance. This integration is implemented through the Single Day-Ahead Coupling (SDAC) and Single Intraday Coupling (SIDC), which coordinate trading across national borders to create a unified, cross-zonal electricity market. Within this integrated framework, Germany and Luxembourg form a single bidding zone with a uniform pricing mechanism. NRW and BW are fully embedded in this wider European electricity market.

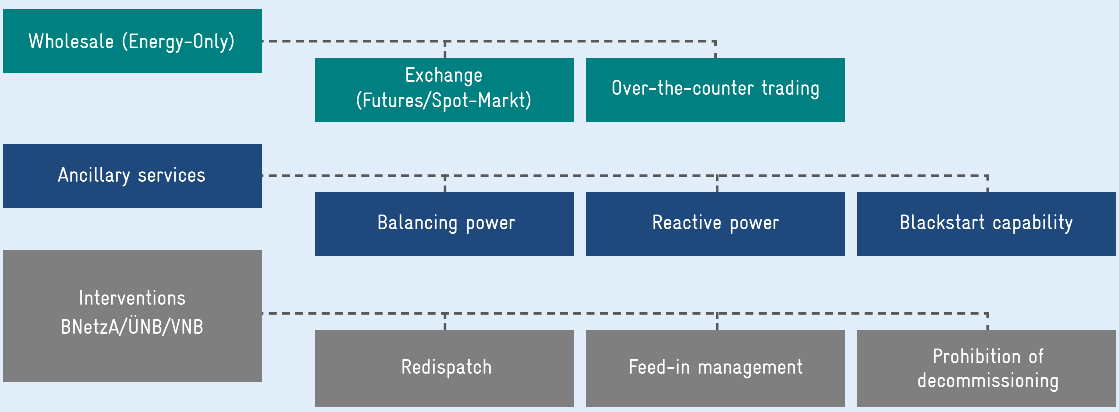
The design of the spot market plays a critical role in enabling short-term flexibility within the power system. Greater product granularity improves the ability of market participants to manage flexibility and respond to real-time imbalances between supply and demand. Continuous intraday trading on EPEX SPOT supports this by allowing participants to adjust their positions in near real time. Trading is possible up to 30 minutes before delivery for cross-border transactions, and as close as 5 minutes before delivery within German control zones.

EU market design has been continuously improved. Until recently, SIDC was limited by a 60-minute gate closure (T–60). However, under the EU Electricity Market Design reform adopted in June 2024, this constraint is being revised. From 1 January 2026, the cross-zonal intraday gate closure time must be no later than 30 minutes before delivery (T–30). This change enhances short-term market liquidity and allows better integration of variable renewable energy sources by enabling closer-to-real-time balancing.

A highly interconnected EU electricity market is itself one of the most important sources of flexibility for Germany and Europe. NRW and BW already benefit from the current high levels of market liquidity and competitive cross-border electricity trading. Ongoing improvements in EU market coupling and the granularity of spot market products will further increase opportunities to monetise flexibility and accelerate its deployment across the system.

Box 3

Excursus: Other measures for ensuring system flexibility and grid stability



While the energy-only market determines electricity prices and dispatch, ancillary services ensure the security and stability of the grid. These services are mostly procured by TSOs. The main categories include:

- Regelenergie (Balancing energy): Used to balance short-term deviations between generation and consumption.
- Blindleistung (Reactive power): Maintains voltage stability within the grid.
- Schwarzstartfähigkeit (Black-start capability): Ensures that parts of the system can restart independently after a blackout.

When the result of the energy-only market leads to grid congestion, e.g., because a lot of wind power is generated in Northern Germany but most of the load is in the South and West, system operators intervene directly to ensure the physical match of supply and demand in all regions.

Key interventions include:

- Redispatch: Adjusting the output of generators to relieve network congestion.
- Einspeisemanagement (Feed-in management): Curtailing renewable generation when grid capacity is insufficient.

In addition, the Federal Network Agency (BNetzA) may issue a Stilllegungsverbot (Prohibition of shutdown): Temporarily preventing the closure of system-relevant power plants to maintain security of supply. This may both relate to the market as a whole or to specific regions, based on network constraints.

Capacity Mechanisms

While the EOM can, in principle, provide incentives for investment in controllable generation and other flexibility options, stakeholder confidence in its effectiveness has declined (BMWE, 2025b). [10]

Articles 21 and 22 of Regulation (EU) 2019/943 permit the introduction of capacity mechanisms by Member States where resource adequacy to satisfy power demand at all times cannot be ensured by the EOM alone. A capacity mechanism is defined as a measure designed to secure the necessary level of resource adequacy by remunerating resources for their availability, excluding measures related to ancillary services or congestion management. Under the Electricity Market Design reform, Member States introducing such mechanisms are required to facilitate the participation of 'non-fossil' flexibility resources, including demand response and energy storage.

The German government has recently committed to launching a national capacity mechanism by 2027 (Kloth, 2025). This mechanism will remunerate providers not only for electricity delivered, but also for their availability during periods of system stress. Following EU legislation, it has to be technology-neutral, enabling participation by all forms of flexible capacity. In terms of design, the federal government released a paper outlining four alternative models for financing investment in controllable capacity (BMWK, 2024):

- Capacity-hedging mechanism (KMS): Suppliers are required to hedge their electricity sales against price spikes.
- Decentralised capacity market (DKCM): Suppliers must secure capacity for their customers by incentivizing demand reduction during peak periods, self-provision, or purchasing capacity certificates.
- Centralised capacity market (ZKM): State-run auctions for capacity with long-term contracts.
- Combined capacity market (KKM): A decentralised capacity market combined with a central component for particularly capital-intensive dispatchable capacities

Recent policy discussions suggest starting with the centralised capacity market model (ZKM) due to its ease of implementation, with plans to refine the mechanism over time (BMWE, 2025c).

10 An exception is observed in the case of large-scale battery projects, for which grid connection requests totaling 400–500 GW have been submitted,far exceeding foreseeable system needs. This surge was primarily driven by short-term price differentials between day and night within the EOM.

Dynamic electricity tariff

Directive (EU) 2024/1711 (2024) require electricity suppliers across all Member States to offer dynamic pricing contracts to customers with smart meters from 2025 onwards. These contracts enable households and businesses to align their consumption with wholesale market price signals.

In Germany, from 1 January 2025 (§ 41a EnWG (2025)), suppliers must provide at least one time-variable tariff—either dynamic or time-of-day based—to households equipped with smart meters. Such tariffs will enable technologies such as heat pumps, BEVs and home battery storage to shift demand to periods of lower prices. In addition, battery storage and vehicle-to-grid (V2G) technologies can feed electricity back into the grid during periods of high residual load, supporting system flexibility and strengthening the integration of renewables. Thus, the roll-out of dynamic tariffs could be a cornerstone of DSF in Germany. It will reduce costs for consumers, facilitate more efficient use of network infrastructure, and support higher levels of renewable energy integration into the power system.

5.5 Key challenges for providing system flexibility

The expansion of dispatchable generation capacity is complicated by persistent uncertainty over future technology pathways. The removal of a clear hydrogen-ready requirement for new plants, coupled with the renewed policy focus on CCS/CCU for gas-fired generation, has created dual uncertainty about the long-term compatibility of new assets with national decarbonisation goals. Environmental organisations have voiced concern that the inclusion of CCS/CCU could lock in reliance on fossil fuel generation rather than accelerating the transition towards clean, flexible backup capacity and other flexibility options, such as demand response and storage.

This policy ambiguity has weakened investor confidence and delayed final investment decisions, slowing the commissioning of peaking and reserve capacity that may be needed between 2030 and 2035. At the same time, a wider debate has emerged over whether current expansion targets for dispatchable gas capacity are proportionate to actual system requirements. The continuing lack of clarity on both technology choices and capacity needs has deepened uncertainty in policy direction—impeding timely investment and constraining progress in the broader development of system flexibility.

Challenges to the scaling up of grid-scale energy storage capacity arise primarily from the slow connection to the grid. The market currently provides strong incentives due to intra-day price difference often exceeding 100 / MWh, as evidenced by several hundreds of GW of grid connection requests. For demand-side storage, the most important challenge is the slow roll-out of smart meters, along with the absence of a clear and stable long-term regulatory framework and the lack of effective investment incentives. The current legal classification of batteries as producers or consumers at different times, unless they only store green electricity, exposes operators to network charges and levies, thereby undermining the economic viability of storage investments (PV Magazine, 2025). The regulator BNetzA is now intending to improve this situation. Moreover, Germany's single national bidding zone obscures regional price differences and congestion signals, meaning that storage assets, such as pumped hydro and batteries, as well DSF providers do not always receive the locational market signals needed to operate where and when they deliver the greatest system value (Bakkenbüll, 2025).

The effective use of DSF in system flexibility is further constrained by infrastructural and regulatory barriers. The slow rollout of smart meters continues to hinder real-time communication between consumers and grid operators, delaying the implementation of dynamic electricity tariffs and automated demand-side response (DSR). For small and medium-sized enterprises (SMEs) and households, participation in flexibility markets remains limited by insufficient financial incentives and, in some cases, by restrictive market-entry requirements. Current market rules impose minimum bid sizes and delivery durations that effectively exclude smaller participants, thereby limiting the activation of DSF potential across the power system without the service of aggregators (Gschwendtner, 2023). For aggregators, many potentials are not (yet) attractive due to the insufficient financial incentives mentioned above.

6 Grid Infrastructure for Power System Transition

A persistent regional imbalance remains between the concentration of wind capacity in northern Germany and the major demand centres in the south and west. In addition, PV capacity is concentrated in the south east and north east. Expanding and reinforcing transmission grid capacity is therefore essential to relieving these bottlenecks and enabling the effective integration of renewable energy into the system. In parallel, accelerating the rollout of smart meters can unlock flexibility from DSF (Section 5.3), helping to balance the system and reduce the need for costly grid interventions (IEA, 2025a). In this area of grid infrastructure too, an integrated planning following the energy efficiency first principle is required.

This chapter provides an overview of the grid infrastructure in Germany, NRW and BW. As the grids in both states are closely integrated into Germany's national network, technically, politically, and in terms of planning, the chapter draws on relevant national developments. It begins with an overview of the current electricity grid and planned grid development as well as the challenges associated with the grid development, followed by an explanation of the grid development planning process. The chapter then presents smart meter and grid initiatives in the two states.

6.1 Overview: The electricity grid in Germany, NRW and BW

The electricity grid in Germany is divided into a transmission and a distribution grid with 4 voltage levels:

- Extra-high voltage (transmission grid): 220 kV/380 kV
- High voltage (distribution grid): 60-110 kV
- Medium voltage (distribution grid): 6-60 kV
- Low voltage (distribution grid): 230 V/400 V-6 kV

It is closely integrated into the wider European power system through extensive cross-border interconnections and subsea cables. The total grid length amounts to around 1.9 million kilometres (2022), with the low-voltage network accounting for the largest share, approximately 1.25 million kilometres (2020). At the state level, the distribution grid in NRW spans 328,799 kilometres, while BW operates a network of 224,949 kilometres, covering high-, medium-, and low-voltage levels (BDEW, n.d.; Bundesnetzagentur, n.d.-b; EnBW, 2025c).

The planning and operation of Germany's electricity grid follow the n-1 security criterion, which underpins the system's high level of reliability. It requires that the grid be capable of withstanding the failure of any single critical component without causing widespread disruptions, through the provision of sufficient network redundancy and reserve capacity.

There are four transmission system operators (TSO) in Germany which run the transmission grid: Amprion, 50Hertz, TenneT and TransnetBW. NRW is located in the Amprion and Tennet regulation zone; BW is located in the TransnetBW regulation zone. The distribution grid in Germany is operated by more than 800 distribution grid operators (DSO) of various sizes; in NRW and BW, there are more than 100 distribution grid operators each (Bundesnetzagentur, n.d.-b; NRW.Energy4Climate, 2025a; UM - BW, 2024c).

In the context of the energy transition in Germany, new challenges are being posed to the electricity grid: First, the future electricity demand is expected to increase, mainly due to increased electrification of applications in industry, transportation and buildings. This implies higher electricity transmission volumes in the future. Second, electricity from wind power will become increasingly important in the future, especially in Northern Germany due to the comparable low costs in this region. This wind power generated in Northern Germany has to be transported to the large electricity consumers, which are mainly located in the south and west of Germany. Third, there will be a higher feed-in from renewable energy sources in the future, which poses challenges especially in the distribution grid.

To address these challenges, Germany must pursue a comprehensive expansion, reinforcement and optimisation of both the transmission and distribution grids. Grid development follows the NOVA principle (Netzoptimierung vor Verstärkung vor Ausbau), which prioritises network optimisation before reinforcement and expansion (Bundesnetzagentur, 2016). This approach is sometimes extended to the NOXVA principle, which incorporates flexibility measures (X) as a preferred option after optimisation but ahead of conventional reinforcement and expansion to make more efficient use of existing grid infrastructure.

Table 2 summarises the planned reinforcement and expansion of the German electricity network to 2045,relative to today's system, together with the associated investment requirements. These network development plans are defined by the transmission and distribution system operators through the national network development planning process.

According to system operators and the Federal Network Agency (BNetzA), a major reinforcement and extension of both the transmission and distribution networks will be required to accommodate rising electricity demand and the growing share of variable renewables. The offshore transmission network, in particular, will require a substantial build-out to connect new offshore wind capacity to the onshore system. Overall, these network development measures are projected to require around EUR 550 billion in cumulative investment by 2045, underscoring the scale of infrastructure expansion needed to enable a secure, flexible and renewables-based power system.

Table 2 Expansion and reinforcement of the transmission and distribution grid in Germany, until 2045 (50Hertz Transmission GmbH et al., 2023; BDEW, 2025; Bundesnetzagentur, 2025b)

Grid	Today (km)	Grid development until 2045		
		Reinforcement network(km)	Expansion network(km)	Investment (€)
Transmission onshore	38,000	10,185	9,173	156.1 billion
Transmission offshore	2038	20,200		157.5 billion
Distribution	1,902,000	502,300		237 billion

For NRW and BW, publicly available information on network expansion and reinforcement remains limited, as most data are aggregated at the federal level. For example, In NRW, part of the planned transmission network expansion is linked to a federal plan for nine offshore connection lines, which will transport electricity from North Sea wind farms to the state via high-voltage direct current (HVDC) underground cables. By 2045, these connections are expected to provide a combined capacity of up to 18 GW, with implementation proceeding gradually from the early 2030s (MWIKE - NRW, n.d.-c). For the high-voltage distribution network in NRW, a minimum investment of EUR 5.6 billion is planned by 2045, encompassing the reinforcement and expansion of approximately 2 800 km of network infrastructure (ibid.).

Key challenges in terms of grid development both in NRW and BW are in particular (Amprion GmbH, 2023; MWIKE - NRW, n.d.-c; Rehtanz et al., 2014; UM - BW, n.d.):

- High investment costs for grid development
- Long planning and approval processes
- Low acceptance of grid expansion
- Necessary harmonization with gas grid planning
- Necessary harmonization of planning at transmission and distribution grid level
- Lack of complete database, especially for distribution grids
- Competing land use demands, including from wind energy
- Shortage of skilled workers
- Shortage of materials
- Increasing number of procedures for the disposal of munitions of war and associated organizational challenges in implementing the procedures (lack of standardization, long processing times)

- Insufficient staffing of the competent authorities due to increasing number of procedures, in particular of the expropriation authorities
- Different regulatory responsibilities for electricity transmission and conversion facilities

While certain challenges can be addressed at the state level—such as improving procedures for the disposal of munitions of war, strengthening the staffing and capacity of permitting authorities, and enhancing local coordination mechanisms—others require federal intervention. In particular, reforms to planning and approval procedures, strategies to increase public acceptance, and efforts to harmonise network planning across transmission and distribution levels must be coordinated within the national network development planning framework.

6.2 Process for the grid development planning in Germany

The network development planning process is regulated at the federal level and applies uniformly across all German states, including NRW and BW.

Transmission network planning

As illustrated in Figure 4, the planning process for the transmission network consists of five main steps. The first three assess the required grid development, while steps four and five cover project implementation.

Step 1: Definition of the scenario framework

The process begins with the development of a scenario framework, which defines alternative pathways for the evolution of the German and European energy systems up to 2045. The framework is prepared by the TSOs and approved by the Federal Network Agency (Bundesnetzagentur, BNetzA) following public consultation (BMWE, 2025a).

Figure 4 Process for transmission grid development planning in Germany (for grid development projects crossing federal or state borders) Own figure based on information from here: (BMWE, 2025a).

Step 2: Network Development Plan (NEP)

Based on the approved scenario framework, the Network Development Plan (NEP, Netzentwicklungsplan Strom) is prepared every two years. The NEP sets out all reinforcement and expansion measures necessary to ensure the continued safe and reliable operation of the electricity network. The BNetzA reviews the draft plan and formally confirms, amends, or rejects individual projects (BMWE, 2025a). The projects summarised in Table 2 reflect the most recent NEP results.

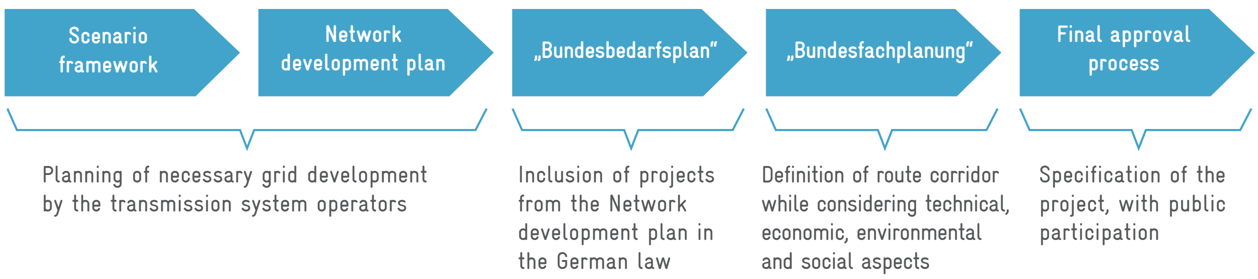
Because of increasing interdependencies between the electricity and gas (natural gas and hydrogen) systems, the network development plans for both sectors are now harmonised to ensure consistent cross-sectoral planning (Grid Development Plan Electricity, 2024).

Step 3: Inclusion in federal law

The Federal Parliament subsequently decides on the inclusion of confirmed projects in the Federal Requirements Plan Act (Bundesbedarfsplangesetz, BBPlG), normally every four years or earlier if required. Projects listed in the BBPlG are designated as critical to the energy transition and of overriding public interest, providing the legal basis for accelerated implementation. The law defines the starting and end points of new high-voltage lines, though route alignment is determined later in the process (BMWE, 2025a).

Step 4: Route corridor definition

BNetzA determines a route corridor, typically 500–1,000 metres wide, based on technical, economic, environmental, and social criteria. This process is known as Bundesfachplanung.



Step 5: Final project approval

In the final step, project-specific permits are issued, confirming the exact route and design of each project. The approval process includes stakeholder participation and formal consultation with affected authorities (BMWE, 2025a).

For projects entirely within a single federal state, the state authorities, rather than BNetzA, oversee planning and approval. In these cases, the process differs slightly: instead of Bundesfachplanung(see step 4), a regional planning procedure is conducted. In contrast to the Bundesfachplanung, however, the corridor resulting from the regional planning procedure is non-binding for the subsequent approval (step 5) (Bundesnetzagentur, n.d.-a).

Distribution network planning

Planning for the distribution network is governed by the Energy Industry Act (Energiewirtschaftsgesetz, EnWG). Under this legislation, DSOs with more than 100,000 connected customers and those with significant curtailment of wind or solar power must submit Network Expansion Plans (Netzausbaupläne, NAPs) every two years. These plans detail measures for optimisation, reinforcement, and expansion of distribution networks. Although not all DSOs are required to publish their NAPs, those that do must include data from downstream DSOs, meaning that the aggregated plans cover the entire German distribution network (Ffe, 2025; VNBdigital, n.d.).

Distribution network planning is based on regional energy scenarios that describe the evolution of generation capacity and sectoral energy demand through to 2045. Germany is divided into six planning regions: North, Central, East, West, Bavaria, and South-West. NRW belongs mainly to the Central and West regions, while BW falls primarily within the South-West region and to a small extent within Bavaria (ibid.)

6.3 Smart grids in Germany, NRW and BW

Germany has established a federal regulatory framework to accelerate the deployment of smart grids and digital infrastructure (MWIKE - NRW, n.d.-c; Netze BW GmbH, n.d.; Vattenfall, n.d.):

- Binding rollout quotas for smart meters. By the end of 2032, 95% of regulated user groups, including consumers with annual consumption above 6,000 kWh, producers with installed capacity above 7 kW, and operators of controllable consumption devices such as heat pumps and BEVs, must be equipped with smart meters. Voluntary installation is available for smaller consumers, and from 2025, installation will also be possible at the customer's request.
- Dynamic electricity tariffs. Since 2025, electricity suppliers have been required to offer dynamic pricing, enabling consumers to adjust their consumption in response to real-time price signals (Section 5.4).
- Temporary control of flexible loads. Network operators are permitted to temporarily reduce the power draw of controllable devices to 4.2 kW per customer in order to prevent local grid overloads, while ensuring that essential functions such as BEV charging and heat pump operation remain available.

NRW and BW view smart grids and digitalisation as essential enablers of a successful energy transition. Building on the national framework, the two states have introduced complementary measures to promote smart grid implementation (MWIKE - NRW, n.d.-c; UM - BW, n.d.):

- Stakeholder coordination and knowledge exchange: In BW, the Ministry of the Environment, Climate and Energy funds the Smart Grids-Plattform Baden-Württemberg e.V., a networking and information hub that brings together key stakeholders involved in grid digitalisation and smart energy systems (UM - BW, 2024b). Ongoing projects focus on developing and testing digital infrastructure to enable real-time communication between grid operators, energy suppliers, and flexible consumers.
- Funding and pilot projects: Both states fund pilot projects and real-world laboratories (Reallabore) to demonstrate smart grid applications under real operating conditions. For example, NRW supports a flagship real-world laboratory in Bedburg, focusing on intelligent sector coupling and smart charging (Box 4).
- Monitoring and evaluation: State-level monitoring tracks technological progress, regulatory performance, and innovation uptake to inform future policy adjustments.

- In addition, NRW offers a bonus scheme for intelligent charging infrastructure integrated with photovoltaic systems and battery storage, explicitly promoting bidirectional charging as part of its broader smart grid implementation strategy (MWIKE - NRW, n.d.-c).

Box 4

Best practice: SmartQuart real-world laboratory, Bedburg (NRW)

The Smart Quart real-world laboratory in Bedburg, NRW, represents one of Germany's flagship integrated smart energy neighbourhood projects, funded by the Federal Ministry for Economic Affairs and Energy (BMWE) (SmartQuart, n.d.-b, n.d.-a).

Located in a resource-efficient settlement with a typical small-town building density, the project demonstrates how cross-sectoral energy systems can supply residential areas in a largely self-sufficient and resource-conserving manner.

Key features and approach

- An integrated, cross-sectoral energy system that supplies households within the neighbourhood in a resource-efficient and largely self-sufficient manner, making maximum use of local renewable energy sources and integrating electricity, heating and cooling, digital networks, and emission-free mobility services.
- Use of a digital district energy management system to monitor and optimise the energy supply in real time, with all components, including distributed generation, storage, and consumption units, connected through a smart digital network that enables seamless coordination and efficient operation.
- Consumer engagement and transparency: Each household has access to a personal dashboard displaying real-time information on energy consumption, availability, and generation. This promotes behavioural adaptation, allowing residents to optimise their energy use in line with system conditions and price signals.

Despite growing policy attention, implementation across the federal states has been hindered by technical, regulatory and capacity-related constraints (IEA, 2025b; MWIKE - NRW, n.d.-c; Smart Grids-Plattform Baden-Württemberg e. V. (SmartGridsBW), 2022):

- Smart meter rollout: Germany's smart meter deployment has focused on quality, safety, and comprehensive functionality instead of speed. Therefore, it has been slow compared with other European countries, constrained by legal and regulatory hurdles as well as bureaucratic delays. In addition, limited stakeholder engagement and enduring concerns about data privacy and cybersecurity have further slowed implementation.
- Planning and implementation time. Prolonged planning and permitting processes for implementation measures (e.g., installation of measurement technologies and storage facilities), coupled with procurement bottlenecks and the required scale of installations (e.g. smart meters), have slowed deployment and increased implementation costs.
- Skilled labour shortages: A shortage of qualified personnel constrains the ability of system operators, installers and service providers to execute large-scale rollouts.
- Interoperability and standardisation: The lack of uniform technical standards and interoperable interfaces hinders the seamless integration of diverse systems and devices.
- Operational integration. Grid operators face significant challenges in adapting operational procedures to accommodate integrated data acquisition, processing and analytics. The transition also requires partial automation of grid management as well as building digital twins of the grid (EWI & BET Consulting GmbH, 2025).
- Flexibility and sector coupling: The effective deployment of smart grids depends on the availability and market integration of flexible generation and load resources (Section 5.3), as well as on the technical integration of heating systems, charging infrastructure, distributed generation, and emerging gas and hydrogen networks into digital grid architectures.

7 The Social Dimension of Power System Transition in NRW and BW

The transition away from a fossil fuel-based power system is reshaping regional economies and societies across Germany. While both states are firmly committed to the energy transition, their distinct industrial structures, innovation capacities, and labour-market characteristics shape their respective pathways towards a climate-neutral economy. This chapter explores the socio-economic dimensions of the energy transition in NRW and BW, focusing on three interdependent areas: employment, economic diversification, and stakeholder participation.

7.1 Employment

NRW

The Rhenish mining area in NRW is one of Europe's largest lignite-producing regions and historically a cornerstone of Germany's fossil-based industrial system. Yet, its economic significance has declined markedly in recent years. In 2017, lignite mining and power generation accounted for only 0.6% of regional value added and directly employed fewer than 10,000 workers, equivalent to roughly 0.3% of the total regional workforce (Oei et al., 2020). While the macroeconomic dependence on coal is now limited, the social and regional implications of the phase-out remain considerable, particularly in communities historically shaped by coal production and energy-intensive industries. At the same time, the region's industrial transformation is under way. NRW now reports approximately 55,100 people employed in the renewable energy sector across around 1,100 companies, representing about 17% of all German firms active in this field (NRW.Global Business, 2025).

The energy transition represents a structural transformation requiring a highly skilled and adaptable workforce. Employment in the Rhineland has grown by nearly 25% since 1999, demonstrating regional economic resilience. However, the coal phase-out coincides with an acute shortage of skilled labour, estimated at around 400,000 professionals by the regional Chamber of Industry and Commerce. At the same time, the structural transformation is releasing a technically experienced workforce into the labour market. This presents both a challenge and an opportunity. Besides, the shift towards sustainable and digital industry will also generate new occupational profiles, particularly in fields requiring STEM (Science, Technology, Engineering, and Mathematics) competencies.

Such a labour market transformation and the associated skills development require close cross-cluster collaboration between industry, education, and research institutions to ensure that the workforce can adapt effectively to structural and technological change (MWIKE - NRW, 2024a).

Through the Zukunftsdialog (Future Dialogue) process, the state government and key stakeholders have identified the need for proactive, implementation-oriented strategies to overcome skills shortages, bureaucratic barriers, digitalisation gaps, and innovation constraints during transformation (MWIKE - NRW, 2024a). These efforts form part of NRW's broader industrial transformation strategy to align its labour market and education systems with the requirements of a sustainable, digital, and competitive industrial base.

A key initiative supporting this agenda is "Kein Abschluss ohne Anschluss" (KAoA), which ensures that young people receive structured career guidance and access to vocational training opportunities. The programme aims to prevent school-to-work dropouts and promote equitable participation in the labour market. By connecting schools, vocational colleges, and industrial partners, KAoA facilitates early engagement with emerging professional fields and enables young people to actively shape the future of work in a low-carbon economy.

The collaborative and innovation-driven approach is further reflected in the vision to establish an "Innovation Valley" in the Rhenish mining area, inspired by the model of Silicon Valley. The initiative seeks to create a high-performing regional innovation ecosystem that fosters value creation, employment, and technological leadership, while aligning industrial development with climate and resource protection objectives (Schulze-Steinen et al., 2023).

BW

Industry constitutes a foundational pillar of BW's economy. With over 1.5 million people employed across roughly 49,000 industrial enterprises, the sector contributed 31.1% of gross value added in 2023, well above the national average of 22% (UM - BW, 2025b). The industrial landscape is strongly weighted toward investment goods, especially mechanical engineering, automotive manufacturing, and electrical engineering, which together account for approximately 64% of industrial revenues (UM - BW, 2025b). A large portion of production is export-driven: 63% in mechanical engineering, 77% in automotive, and 62% in electrical engineering (ibid.).

In terms of workforce distribution, mechanical engineering is the largest industrial employer (22.1% of the industrial workforce), followed by automotive manufacturing (19.6%) and the electrical industry (16.2%). Other important segments include metal production and processing (11.8%), food industry (5.0%), chemicals (4.8%), and plastics manufacturing (4.0%) (UM - BW, 2025c).

Unlike NRW, BW's transition strategy gives considerable emphasis to electric mobility, battery technologies, renewables, and digitalisation. A joint position paper by the Environment Ministry and social partners (2025) highlights potential for up to 40,000 additional jobs by 2030 in renewable and energy efficiency sectors, conditional on consistent climate policy and accelerated implementation that link diversification to employment growth (UM - BW & Deutscher Gewerkschaftsbund Baden-Württemberg, 2025).

A salient indicator is EnBW's plan to hire an additional 10,000 skilled employees by 2026, reflecting the growing demand for new technical competencies in clean energy and systems infrastructure (EnBW, 2025b). To address regional skilled labour shortages and complementing firm-level efforts, the state engages in system-level coordination via the Fachkräfteallianz Baden-Württemberg, founded under the auspices of the state's economic ministry. The Alliance brings together over 40 partners, including industry organisations, trade unions, municipal actors, employment agencies, and ministries, to jointly address workforce supply, vocational training, continuing education, and integration of underutilised labour pools (WM - BW, 2025).

In general, the labour market transformations under way in NRW and BW are closely aligned with broader national and European policy agendas on climate neutrality, digitalisation, and inclusive economic growth.

At the national level, Germany's Climate Action Plan 2050 and the National Skills Strategy emphasise the importance of upskilling and reskilling the workforce to meet the demands of a low-carbon and digital economy. At the European level, the European Green Deal, the Pact for Skills, and the Just Transition Mechanism provide both strategic direction and financial instruments to support workforce adaptation, technology deployment, and regional economic diversification. Together, these frameworks create a coherent policy environment that underpins the ongoing industrial transformation in Germany's key manufacturing regions.

7.2 Economic diversification and innovation

NRW

The structural transformation of NRW's coal regions requires the development of a new economic focus built on innovation and sustainability. According to the state's vision statement ("Leitbild"), strategic investment in renewable energy, hydrogen technologies, and circular-economy industries is central to establishing new research and development hubs, attracting private capital, and creating high-value employment opportunities (MWIKE - NRW, 2024a).

The Zukunftsagentur Rheinisches Revier (ZRR) serves as the principal coordinating body for this transformation. Its mandate includes strategic planning, technical support, and the implementation of the multi-year Economic and Structural Programme (WSP). More than EUR 14.8 billion in structural-strengthening funds from federal and state budgets have been earmarked for sustainable development projects in the Rhenish mining area through 2038. The support is grounded in the broader "Strukturstärkungsgesetz Kohleregionen" (StStG) and "Investitionsgesetz Kohleregionen" (InvKG) framework, which together provide a nationwide funding commitment of up to EUR 26 billion to support coal-region transformation (Rheinisches-Revier, n.d.).

In addition, NRW integrates the European Regional Development Fund (ERDF) and the Just Transition Fund (JTF) into a unified ERDF-JTF NRW 2021–2027 programme, designed to advance a climate-neutral and resource-efficient transformation, foster innovation and digitalisation, and strengthen social and regional cohesion (MWIKE - NRW, 2025a). Regio. NRW – Transformation is a flagship call under this programme. It promotes pilot and model projects that advance innovation, sustainable business models, and climate-friendly solutions across multiple districts. By fostering knowledge transfer from research institutions to SMEs, encouraging circular-economy initiatives, and supporting urban energy-transition projects, Regio.NRW strengthens the resilience, adaptability, and competitiveness of regional economies. Together, these place-based strategies illustrate how structural change can be managed in a socially inclusive and economically sustainable manner (In.NRW, 2025).

Furthermore, NRW is rapidly scaling up its hydrogen economy through its Hydrogen Office (H2.NRW), acting as a central hub for support, networking, and funding for companies, municipalities, infrastructure developers, and mobility providers (NRW.Energy4Climate, 2025b). The strategy emphasizes building import corridors, deploying gigawatt-scale electrolysers, and supporting pilot projects in industry and transport, with the goal of reducing greenhouse gas emissions while generating economic growth and up to 130,000 new jobs (MWIKE - NRW, 2025b).

BW

BW is consolidating its position as a leader in sustainable industrial transformation (EnBW, 2025a). The state is strengthening its GreenTech leadership by advancing environmental and low-carbon technologies, while simultaneously investing in the hydrogen economy to establish hydrogen as a key energy carrier for industry and transport (Fraunhofer ISE, 2025; ZWS, 2025b).

BW's strategy builds on its strong industrial and technological base, focusing on developing advanced solutions for renewable-energy integration, energy storage, and smart-grid technologies. Its extensive research and innovation ecosystem plays a central role in pioneering low-carbon processes and technologies, thereby reinforcing the state's competitive advantage within the emerging global green economy.

Several leading research institutions anchor this innovation ecosystem. The Fraunhofer Technology and Innovation Campus S-TEC in Stuttgart and the Karlsruhe Institute of Technology (KIT) are key to BW's roadmap for establishing a long-term hydrogen innovation hub. The state's Hydrogen Roadmap BW and the H2BW platform, launched in 2021, coordinate projects across the entire hydrogen value chain, from pilot initiatives to large-scale regional model projects, with a total budget of approximately EUR 500 million (BW, 2025a).

Complementing these efforts, the "Innovationsallianz Baden-Württemberg" (innBW) brings together 10 application-oriented research organisations with 12 institutes, acting as a bridge between science and industry. It facilitates technology transfer and transforms research outcomes into market-ready products, processes, and services (innBW, 2025). The Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) contributes to this network through its work on artificial intelligence and machine-learning applications in the energy sector, including feed-in forecasting, system optimisation, and process efficiency for fuel cells, batteries, photovoltaic modules, and electrolysers (ZWS, 2025a).

The Smart Grids Platform Baden-Württemberg e.V. further demonstrates BW's commitment to digitalisation and stakeholder collaboration in the energy transition. It connects actors from industry, academia, and policy to accelerate smart-grid deployment and strengthen the state's broader objectives of energy-system flexibility, reliability, and integration (SmartGridsBW, 2025).

To further support transformation in the automotive and e-mobility sectors, BW has established a coordinated framework that brings together industry, research, and government actors.

The Strategiedialog Automobilwirtschaft BW (SDA-BW), launched in 2017, serves as a strategic dialogue platform uniting OEMs, suppliers, trade unions, academia, and government agencies. It has initiated over 70 projects covering vehicle electrification, digital mobility services, sustainable supply chains, and SME transformation support (Verkehrsministerium Baden-Württemberg, 2025). The state agency e-mobil BW acts as the state's central innovation and network hub for new mobility and energy technologies. It operates several transformation hubs, including scale-up E-Drive, which supports SME suppliers in repositioning towards electric powertrain markets (e-mobil BW GmbH, 2025).

7.3 Governance and stakeholder participation

Stakeholder Landscape and Policy Narratives

A diverse constellation of actors at the state level shapes the policy narratives surrounding the energy transition in both regions, each exerting influence over its pace, priorities, and public acceptance (Schulze-Steinen et al., 2023).

- Government institutions—including state ministries, regulatory authorities, and local administrations—drive the transition through legislation, funding programmes, and information campaigns. Their narratives typically emphasise economic opportunity, climate protection, and energy security.
- Industry associations also play a central role. Organisations representing energy suppliers (e.g. BDEW, German Association of Energy and Water Industries), renewable energy industries (e.g. BEE, German Renewable Energy Federation; LEE NRW, Renewable Energy Association of North Rhine-Westphalia; and Plattform Erneuerbare Energien BW, Renewable Energy Platform Baden-Württemberg), and energy-intensive sectors (e.g. BDI, Federation of German Industries) advocate for investment security, competitiveness, and a stable regulatory framework.
- Trade unions, particularly IG BCE (Mining, Chemical and Energy Industrial Union), are pivotal in ensuring a just transition for workers in fossil fuel industries. Their narratives stress the importance of social compatibility, employment protection, and retraining opportunities.
- Environmental NGOs, such as BUND (Friends of the Earth Germany) and NABU (Nature and Biodiversity Conservation Union), push for ambitious climate goals and rapid renewable energy deployment, highlighting ecological urgency and the benefits of a fossil-free future.
- Research institutions and think tanks contribute scientific expertise that directly informs policy. Organisations such as the Wuppertal Institute (NRW) and Fraunhofer ISE (BW) provide analytical foundations, modelling, and evidence-based recommendations that shape strategic decision-making.

Policy processes- Stakeholder dialogues

Policy processes in both NRW and BW are characterised by a strong culture of dialogue between government, industry, and research institutions, reflecting the innovation-driven nature of their regional economies.

NRW has developed a comprehensive framework of initiatives to advance its transition towards climate neutrality. IN4climate. NRW, launched in 2018, serves as a cross-sectoral platform promoting the decarbonisation of energy-intensive industries through structured cooperation among industry, government, and academia. Its affiliated think tank, SCI4climate. NRW, coordinated by the Wuppertal Institute, provides scientific analysis and policy support for industrial transition strategies (Wuppertal Institut, 2025). In 2021, the state established NRW. Energy4Climate, succeeding the former NRW Energy Agency, to act as the central coordinating body for climate and energy transition policy. In 2022, IN4climate.RR was set up that extends this approach to the Rhenish coal mining region, linking structural transformation with the wider industrial transition and positioning the area as a model region for climate-neutral industry.

At the regional level, the Zukunftsdialog exemplifies a participatory governance model. It supports bottom-up processes by engaging municipalities, businesses, trade unions, civil society, and academia in designing and implementing sustainable development strategies.

In addition, the extensive social dialogue that accompanied coal phase-out, bringing together trade unions, industry representatives, and government authorities, serves as an important precedent for managing future structural transitions in a socially balanced and economically viable manner.

Together, these initiatives ensure that NRW’s industrial and social transformation proceeds in a coordinated, inclusive, and evidence-based manner.

BW has established a similarly collaborative governance architecture, aligning climate neutrality with industrial innovation. The Climate Protection Foundation BW (2021) supports the transition through funding for businesses and research institutions, education initiatives, and projects that enhance natural carbon sinks.

The Climate Protection and Energy Agency Baden-Württemberg (KEA-BW) functions as the central coordination body for state-level climate action. It provides strategic and technical support to municipalities, facilitates access to information and funding, and fosters cooperation among stakeholders from government, industry, academia, and civil society (KEA-BW, 2025).

Through its Innovation and Future Agenda, aiming to set international benchmarks in the deployment of future-oriented technologies (BW, 2025a). Since its inception in 2014, the programme has mobilised approximately EUR 20 billion in public and private investment, driving research, innovation, and industrial transformation across key sectors (ibid.). This agenda is underpinned by a series of sectoral strategic dialogues, most notably the Strategic Dialogue for the Automotive Sector (SDA), which promotes consensus-building between government, industry, science, and social partners. Similar participatory mechanisms guide initiatives such as the Smart Grids Platform Baden-Württemberg and the state's Smart-Grid Roadmap to 2040 (SmartGridsBW, 2025). Broader dialogues covering agriculture, healthcare, and construction further embed public engagement, complemented by citizen-dialogue formats that strengthen democratic participation in the energy transition.

Finally, the Initiative Wirtschaft 4.0 acts as a coordinating platform for digital transformation, ensuring that decarbonisation and digitalisation advance in tandem across the regional economy (Wirtschaft digital BW, 2025).

Citizen Engagement and Public Acceptance

Citizen-led initiatives and local organisations play a pivotal role in shaping public acceptance of the energy transition. As grassroots movements, they can both facilitate and challenge energy projects, depending on local context and perceived social or environmental impacts.

In NRW, public attitudes towards the transition are shaped by the region's industrial heritage and coal-dependent past. While resistance to coal phase-outs has been evident in some communities, there has also been a strong emergence of local renewable energy initiatives. The state's dense urban and industrial landscape creates constraints for onshore wind deployment, leading to land-use conflicts and instances of local opposition. At the same time, a growing movement of citizen energy cooperatives enables residents to co-invest in and collectively own renewable energy projects- momentum that is strengthened by the Bürgerenergiegesetz NRW, which makes local financial participation in new wind projects the norm. This participatory model has proven effective in enhancing local acceptance by linking economic benefits to environmental objectives (BUND, 2025).

BW has a long-standing tradition of civic engagement and participatory governance. The state's diverse and densely populated landscapes present specific challenges for the expansion of renewable energy and grid infrastructure, making public acceptance and spatial planning critical factors for successful implementation (European Energy Forum, 2025). Nevertheless, BW benefits from a robust network of environmental associations and citizen-led energy initiatives, coordinated through platforms such as Bürgerenergie Baden-Württemberg, which promote community-based renewable energy projects and transparent stakeholder dialogue (Bürgerenergie, 2025).

Both NRW and BW are making steady progress towards the decarbonisation of their power systems while maintaining employment and strengthening industrial competitiveness. In NRW, the transition of its coal region marks a deep structural transformation towards a more diversified and innovation-oriented economy, supported by substantial public investment and comprehensive regional development programmes. BW, by contrast, is building on its strong industrial base and world-class research ecosystem to accelerate GreenTech innovation and deploy low-carbon technologies across key manufacturing sectors. In both regions, coordinated governance frameworks, structured stakeholder dialogue, and active citizen participation to ensuring that the transition remains inclusive, economically robust, and consistent with long-term climate-neutrality objectives.

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