Annual Report 2024

Germany

Photo: *Completed Wind Energy Research Test Field WINSENT (Source: ZSW/David Arzt)*

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The installed capacity of renewable energy systems increased by nearly 20 gigawatts to a total of nearly 190 gigawatts. Compared to the previous year, this represents an increase of 12 percent. The main contributors to this development were the energy sources solar and wind.

The approval procedures have been consistently simplified and expedited since 2022 to achieve further independence from fossil energy imports and to protect the climate. In 2024, nearly 15 gigawatts of land-based wind energy were granted permits – a record that is nearly 90 percent higher than 2023 (8 gigawatts).

This is a significant increase for the second consecutive year, suggesting rising installation numbers in the coming years. Around 72 gigawatts of onshore capacity were installed in 2024. Between May and September 2024, 73 offshore wind turbines were commissioned. These include the Baltic Eagle offshore wind farm in the Baltic Sea and the Gode Wind offshore wind farm in the North Sea.

In 2024, a total power output of 0.7 gigawatts was put into operation. This means that in 2024, more than twice the offshore wind capacity was added com-

Total (net) installed wind power capacity	72.786 GW
Total offshore capacity	9.215 GW
New wind power capacity installed	4.05 GW
Decommissioned capacity (in 2024)	0.712 GW
Total electrical energy output from wind	138.9 TWh
Wind-generated electricity as percent of national electricity demand	26.6 %
Target	80 % renewable energies by 2030
National wind energy RD&D budget	60.894 million USD

Table 1. *Key Statistics 2024: Germany [3], [15], [16]*

pared to the previous year. Overall, 9.2 gigawatts of installed offshore capacity is now in operation in the Baltic and North Seas. [1] [2]

Highlights

- With 254.9 TWh all renewable energies in Germany provided more than 55 percent of the gross electricity consumption in 2024. [3]

- Wind energy was in 2024 the most important renewable energy source in the German electricity mix. [2]

Market Development

Targets and Policy

- The use of renewable energies is a matter of overriding public interest in Germany. With regard to onshore wind energy, Germany aims at reaching 115 GW by 2030 and 160 GW by 2040 [4] [5].

- The Federal Emission Control Act (BImSchG) was adapted in February 2025 including a paragraph for more control and acceptance for onshore wind expansion ("Gesetz für mehr Steuerung und Akzeptanz beim Windenergieausbau") by making clear specifications for site selection. [6]

- Further legislative measures were drafted within existing laws (EEG, Renewable Energy Sources Act (EEG); WindBG, Act on Determination of Area Requirements for Onshore Wind Turbines, ROG/BauGB, SpatialPlanningAct) to ensure the implementation of RED III for onshore wind energy. [7]

- With a new funding guideline, citizens owned energy communities are supported by the Federal Ministry for Economic Affairs and Energy (BMWE) providing simplified procedures and easier access. [8]

- With regard to offshore wind energy, the targets are 30 GW by 2030, 40 GW by 2035 and 70 GW by 2045 according to WindSeeG - Offshore Wind Energy Act [26], however 50 GW by 2035 envisaged by The Federal Maritime and Hydrographic Agency (BSH).

- Germany belongs to the larger North Sea region, which has a significant potential for renewable energies. Offshore wind power will play an increasingly important role in achieving the European energy and climate goals. To achieve these goals, Germany is working with the other NSEC (North Seas Energy Cooperation) countries to identify, analyze, and implement concrete cooperation projects. [4]

Progress and Operational Details

In 2024, onshore wind turbine approvals reached unprecedented heights, with 2,405 turbines with a combined capacity of 14,056 megawatts (MW) newly approved nationwide. This represents a significant increase of 85 percent compared to the previous year. North Rhine-Westphalia emerged as the clear leader, securing 30 percent of the approved capacity, with 4,044 MW.

Despite the surge in approval notices, the processing times in most federal states improved substantially. On average, the approval procedures took 23 months, a ten percent reduction from 2023. The abundance of new onshore approvals also had a notable impact on the tenders. A substantial 90 percent of the auction volume was awarded for 11 GW of capacity, representing a significant increase of approximately 70 percent compared to the previous year.

The average award value of the tender rounds in 2024 is 7.26 ct/kWh (7.33 ct/kWh in 2023). The maximum permissible value for bids in the tenders has been set at 7.35 ct/kWh since 2023 and will remain the same for the tenders in 2025. [9]

Onshore in total, 635 new plants with a combined capacity of 3,251 MW were connected to the grid. Commissioning figures declined by nine percent compared to 2023, while the repowering share increased to 37 percent. Consequently, the decommissioning figures reached a new high, with 555 old turbines with 706 MW finally decommissioned in 2024. [10]

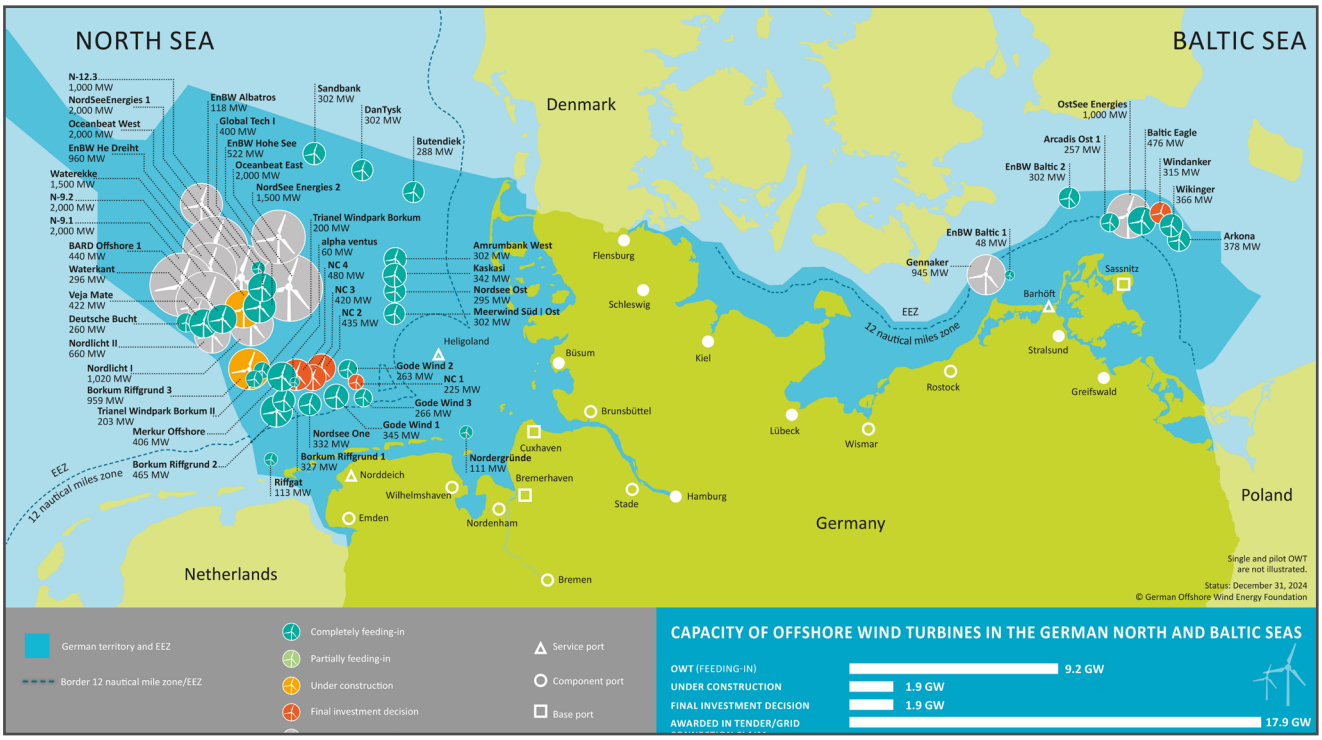

Figure 1. *Capacity of offshore wind turbines in the German North and Baltic Seas (Source: German Offshore Wind Energy Foundation.)*

On average, wind turbines installed in 2024 have a rated power of 5,112 kW and a total height of 216 m. This represents a 7 percent increase in turbine output and a 5 percent increase in total height compared to the average turbine configuration of 2023. These trends continue. The average rotor diameter is 146 m, and the hub height is 143 m. The specific power averages 302 W/m². [9]

Onshore wind capacity, combined, reached 63.571 GW (60.976 GW in 2023). This generated 110.565 GWh (115.565 GWh in 2023) of net electricity, meeting approximately 26.5 percent of the 2024 public net electricity generation of 416.8 TWh. [11],[12]

As of December 31, 2024, German waters are home to 1,639 offshore wind turbines (OWTs) with a combined capacity of approximately 9.2 GW. Throughout 2024, 73 new turbines, with a total capacity of 742 MW, were connected to the electricity grid for the first time. [13]

In 2024, offshore wind turbines with an average rated power of 10.2 MW were commissioned, marking a 7 percent increase compared to the previous year. This trend towards increasingly powerful offshore wind turbines continues.

The average rotor diameter of the turbines commissioned in 2024 also increased by 5 percent to 182 m, resulting in a reduction of the specific power to 390 W/m². Additionally, the average hub height increased by 6 percent to 113 m. [13]

At the end of 2024, Germany had 31 fully operational offshore wind energy projects (OWPs). [13]

In June 2024, two offshore wind sites (N-11.2 and N-12.3) with a total capacity of 2.5 GW were awarded to Total Energies (€1.305 million/MW) and EnBW (€1.065 million/MW), respectively, following a dynamic bidding process. In August 2024, three more sites with a total capacity of 5.5 GW were awarded to RWE (N-9.1 and N-9.2) and Luxcara (N-9.3) based on qualitative criteria. [13]

Offshore wind capacity, combined, reached 9.215 GW (8.473 GW in 2023). This generated 25.696 GWh (23.534 GWh in 2023) of net electricity, meeting approximately 6.2 percent of the 2024 public net electricity generation of 416.8 TWh. [11] [12]

RD&D Activities

National RD&D Priorities and Budget

- Germany continues to pursue a very broad R&D programme (8th Energy Research Programme of the Federal Ministry for Economic Affairs and Energy (BMWE) which started in June 2024) rather than focusing on a specific subject.

Two of the main goals are to generate renewable energy efficiently and sustainably and to guarantee a robust grid for a reliable power supply. To this end, several options for wind energy related R&D are considered in this mission-oriented research programme. [14]

- In 2024, the Federal Ministry for Economic Affairs and Energy (BMWE)

started 83 new projects (within 30 new joint projects) with a new funding amount of EUR 52.2 million [15].

- Additionally, a topping-up of EUR 0.89 million [16] for two ongoing projects that started in former years.

National Research Initiatives and Results

- The research project **ReliaBlade2** (0324335H-M) is a collaboration between partners from science and material testing (Fraunhofer IWES, ForWind, and BAM) as well as German rotor blade manufacturers (Nordex, Enercon, and TPI) to improve the reliability of rotor blades through new fatigue models, improved modeling of manufacturing processes, more accurate blade models, and damage-based testing methods.

The improved methods developed in the project allow for better representation of field loads in the certification test and more accurate prediction of the resulting damage. This improves the reliability of wind energy and avoids costly repairs or refits due to prematurely occurring damage. [17], [18]

- The main objective of **EuroWind-Wakes** (03EE3120A-C, CETPartnership Joint Call 2023) is to develop, improve, validate and compare different multi-scale wake modeling techniques based on applied science methods and current industry standards through collaboration between leading international research institutions and to apply them at the scale of the entire North Sea.

The main outcomes of the project are improved and aligned models and guidance on when to use which modeling methodology, taking into account the associated uncertainties in very large-scale cluster wake effects on the North Sea scale. This will support transnational maritime spatial planning and thus make the development of new offshore wind farms in Germany and Europe less risky. [19]

- The project **BesGASa** (03EE2071A-C) aims to accelerate the energy transition by developing wind turbines with grid-forming capabilities. In order to formulate the requirements for decentralized generation plants with grid-forming converters, which will represent the grid connection rules (grid codes) in future, complete knowledge of the capabilities and possibilities of the technology is required.

Wind turbine manufacturers, wind farm operators and grid operators are working together to break the circular relationship by providing scientific support for the project during the wind turbine development phase, publishing findings and supporting standardization. [20]

- The goal of the project **Demir** (03EE3096A-D) is to make the decommissioning of offshore wind farms more efficient and environmentally sustainable, and to provide the research results to the offshore wind industry. OWTs are designed for a nominal lifespan of 20 to 25 years.

Their decommissioning and associated dismantling depends on a range of criteria that should be considered and ultimately included in a technical-economic and risk assessment. This includes the planning requirements of security services, as well as compliance with legal regulations regarding the scope of dismantling.

Another challenge is the highly volatile and limited markets for marine resources and suppliers of decommissioning techniques and procedures. [21]

Test Facilities and Demonstration Projects

- The project **ACC** aims to develop a novel printing process based on a rotating printing system that makes it possible to produce moulds even for very large cast components by means of 3D printing. The aim is to achieve outer diameters of up to 8 meters. In 2024 the large sand 3D printer has been commissioned as a demonstrator. [22]

- In 2024, the Wind Science and Engineering Test Site in Complex Terrain (**WINSENT**) was officially inaugurated on the Swabian Alb. It features four met masts, other measurement equipment and two wind turbines with a nominal capacity of 750 kilowatts each and a rotor diameter of 54 meters at a height of 73 meters, resulting in a total height of 100 meters.

A wind energy test field with such specifications in complex terrain is considered unique worldwide. [23]

Collaborative Research

- The Federal Ministry for Economic Affairs and Energy (BMWE) is the German Contracting Party in the IEA Wind TCP. In 2024, German research institutions and industry representatives were involved in 21 of 25 active Research Tasks (11, 39, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 50, 62 and 63).

Task 52 “Large-scale deployment of LIDAR” is led by a German Operating Agent from Fraunhofer Institute for Wind Energy Systems (IWES). Most of Germany’s Task participants also execute nationally funded projects in their related topics, benefitting the mutual worldwide information exchange within their IEA Wind TCP Tasks and to some extent between different TCPs.

- Furthermore, Germany is Federal partner in the Clean Energy Transition Partnership (CETPartnership). Since the first joint call was launched in 2022, wind energy related topics are included amongst a variety of renewable technologies and system solutions within the Transition Initiative (TRI) 2 “Enhanced zero emission power technologies”.

Yearly calls are foreseen until 2028. Germany is involved in the current ongoing Joint Calls 2024 and 2025. With further granted projects like Hybrid Wind (03EE3102A/B) and EuroWind-Wakes (03EE3120A-C) the collaborative research on European level continues and enhances the IEA Wind TCP. [24] [19] [25]

Impact of Wind Energy

Environmental Impact

- In 2024, the generation of around 139 TWh of wind energy led to a reduction of almost 106 million tons of CO2-equivalent greenhouse gas emissions [11].

- In the project **RKR_Pro** (03EEM2002) the RKR pro model for habitat use and collision risk which was established for the Red Kite will be finalized and analogically adapted to other bird species, like the Sea Eagle, White Stork, Honey Bussard, Black Kite, and Imperial Eagle.

This is done by using modern statistical methods and different input parameters (e.g., habitat preferences, flight altitude distribution, meso and micro avoidance behaviour, usage intensity depending on distance to the breeding site, etc.) to validate the RKR model empirically.

In addition to the GPS-tracked individuals' data, camera and laser rangefinder (LRF) data also were applied in the RKR model. [26]

Economic Benefits and Industry Development

In total, investments in construction of wind power plants increased by 115 percent to 9.05 billion EUR (7.84 billion EUR in 2023). While onshore investments slightly decreased from 5.96 billion EUR in 2023 to 5.47 billion EUR in 2024), offshore wind investments almost doubled to 3.58 billion EUR (1.88 billion EUR in 2023).

Economic stimuli from the operation of wind power plants showed again a constant level: onshore 2.32 billion EUR (2.28 billion EUR in 2022), offshore 0.94 billion EUR (0.76 billion EUR in 2023). [11]

Onshore, Nordex (32 %), ENERCON (30 %), and Vestas (28 %) share almost equally the manufacturer's share of capacity additions in Germany. [9]

The Nordex Group is expanding its product portfolio in the 5 MW segment and launching a turbine variant of its Delta4000 platform. This platform is specially tailored to meet the requirements of the US market. The N169/5.X turbine has a rotor diameter of 169 metres and a power rating of up to 5.5 megawatts. The N169/5.X is particularly suitable for wind regions in the USA with low to medium wind speeds and without intense turbulence. [27]

The Nordex Group has also announced its intention to expand its range of towers for the N175/6.X turbine with a 200 metres hybrid tower. The tower is based on the design of the Nordex hybrid tower, which the company has successfully tested in 2024 with two prototypes and a complete wind farm in Finland. [29]

In 2024, the Nordex Group secured orders from 24 countries, resulting in an average sales price of EUR 0.90 million per megawatt (MW), an increase from EUR 0.84 million/MW in 2023. Europe, with orders from 18 countries, accounted for 79 percent of the total order intake. Germany, Türkiye, and Spain were the largest individual European markets.

The North American region, encompassing Canada, represented 12 percent of the orders, while other world regions, including South Africa, accounted for 8 percent. [30]

ENERCON has launched its top-of-the-line model, the E-175 EP5, the first prototype was installed at one wind farm in North Rhine-Westphalia. This turbine boasts a rotor diameter of 175 metres, a nominal power output of 7.0 MW, and hub heights reaching up to 175 metres.

The E-175 EP5 E2's new separable permanent magnet generator has significantly reduced the turbine's reliance on rare earths. Additionally, the turbine's innovative and efficient pre-assembly, transportation, and installation concept has streamlined the process. [31]

In contrast to ENERCON's generator models so far, this new model features an internal stator and an external rotor that rotates around it. One advantage of this external rotor design is that the rotor rim can be kept relatively narrow due to the permanent magnets. Additionally, ENERCON was able to reduce the length of the active parts by almost 50 percent, which directly impacts material efficiency by reducing the required magnet mass by more than 40 percent. [31]

An automatic blade flange bearing bolting system was put into operation at the plant in Aurich. According to ENERCON this, along with other efficiency measures in the production line for the EP3 and EP5 rotor hubs, has significantly reduced the throughput time of components in the plant. [31]

Next Term

In April 2025 the new Federal Government presented its coalition treaty in which the exploitation of renewable energies was emphasized, including further wind energy expansion. This treaty was signed in May. Therefore, Federal and State Governments are continuously working together to make the energy transition transparent, predictable and pragmatically successful. [32]

Furthermore, with the effective 8th Energy Research Programme the Federal Ministry for Economic Affairs and Energy (BMWE) underlines wind energy RD&D via a mission-oriented approach including cross-cutting aspects that will help optimize the energy system to reach climate neutrality by 2045. This 8th Energy Research Programme is built on applied research for the electricity transition, the heat transition, a progression of the hydrogen economy, and a transfer process for participation and practice orientation. [33]

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