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EVALUATION OF GERMANY'S WIND ENERGY IMPLEMENTATIONS IN THE CONTEXT OF EU ENERGY POLICIES*

Damla UMUR
Manisa Celal Bayar University, Manisa, Turkiye

H. Kutay AYTUĞ*
Manisa Celal Bayar University, Manisa, Turkiye

*CORRESPONDENCE

H. Kutay Aytuğ
kutayaytug@yahoo.com
https://orcid.org/0000-0002-6353-7468

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Abstract

This study initially discusses the researches conducted on wind energy in Europe. The general principles of European Union energy policies were mentioned, and then renewable energy policies were focused on. From 1970 to the present, many important steps have been taken that have led to the current position of Europe's wind energy. These critical efforts are addressed comprehensively. Germany, which has made significant contributions to the development of wind energy in Europe and plays a leading role in this field, has been selected as the country to be examined in this article. Germany stands out with its offshore wind energy technology due to its location in the North Sea. Detailed information was given about Germany's projects in recent years and planned for the future. This paper is a general analysis of the wind energy policies of the European Union, but also of Germany, which follows these policies.

Keywords: EU, Germany, Wind Energy, Offshore

Introduction

When compared to onshore settings, offshore wind farms benefit from stronger and more consistent wind speeds, which results in improved energy efficiency. Because of the North Sea's exceptional wind conditions, turbines may run at higher efficiency rates, improving Europe's grid stability and energy security.

These wind farms supply local energy needs and lessen the need for long-distance transmission infrastructure because they are frequently located close to coastal areas with high population densities. The efficiency of energy supply is increased overall and energy losses are reduced due to the close proximity to industrial and urban hubs.

The growth of offshore wind requires regional cooperation amongst EU members. Cross-border initiatives that encourage energy integration, maximize resource usage, and fortify the EU's internal energy market include hybrid offshore wind farms that span multiple nations.

Additionally, offshore wind energy helps to diversify the energy supply in the region and lessen geopolitical concerns by reducing the EU's reliance on fossil fuels. Offshore wind improves Europe's energy security by lowering dependency on outside energy sources.

In Europe, the offshore wind industry contributes significantly to economic growth and job creation. Significant investments in technology, infrastructure, and human resources are needed to expand offshore wind farms, which creates job opportunities in a variety of industries, including manufacturing and research and development.

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The preservation of maritime biodiversity and ecosystems must be balanced with the growth of offshore wind in order to maintain environmental sustainability. To guarantee that offshore wind growth is in line with efforts to conserve the maritime environment, the EU sets stringent environmental laws. Prioritizing local community engagement also helps to guarantee equitable distribution of offshore wind benefits.

Germany's transition to renewable energy and its attempts to mitigate climate change depend heavily on wind energy, especially offshore wind energy. Germany's energy transition, or Energiewende[1], aims to cut carbon emissions and its dependency on fossil fuels. As a clean, sustainable energy source, wind energy is essential to this shift. Because offshore wind farms produce more energy than onshore wind farms due to the strong, steady winds encountered at sea, offshore wind energy is particularly significant. Germany meets its renewable energy ambitions for 2030 and beyond thanks to its large investments in offshore wind projects, which also significantly contribute to the country's economic growth, energy security, and climate goals.

The first section of this study provides an overview of the European Union's energy policies, detailing the guiding principles, the priority placed on renewable energy, and the key advancements made in wind energy. The second section examines the current state of offshore wind energy, which is particularly crucial for Germany. The final section outlines Germany's future goals in the development of offshore wind energy.

1. EU Energy Policy

This section examines the energy policies of the European Union. A particular emphasis is placed on renewable energy policies. This section covers the principles followed by the European Union on this matter, the importance it places on renewable energy, and the significant steps it has taken in wind energy.

1.1. General Principles of EU Energy Policy

Three guiding concepts form the basis of EU energy strategy. These are competitiveness, supply security, and sustainability. The implemented policies are grouped into seven key categories: renewable energy, energy efficiency and conservation, internal energy markets, energy supply security, environmental preservation, nuclear energy, and research and development. The presentation of the pertinent policies and an explanation of their purpose come first for each category, followed by an introduction that covers significant turning points in its development (Kanellakis, Martinopoulos, 2013, 1020).

The EU is a global leader in renewable energy technology research and implementation. However, according to a report published in 2021, the EU needs to further enhance its global competitiveness. Under the European Green Deal, renewable energy is a key component of the clean energy transition (European Commission, 2024).

Raising energy efficiency targets is crucial for Europe's energy transition. Efficient energy use reduces energy bills, decreases the EU's dependency on external resources, protects the environment, improves quality of life, and contributes to sustainable economic growth. To achieve these benefits, efficiency must be improved throughout the entire energy supply chain, from production to consumption (European Commission, 2024).

The European energy market is non-discriminatory, flexible, customer-focused, and competitive. It focuses on consumer protection, market access, transparency, regulation, interconnections, and supply security. The goal is to ensure a functional market with fair access, strong consumer protection, and sufficient interconnection and generation capacity (European Parliament, 2024).

Energy supply security is a recurring theme in national, European, and global energy strategies. In November 2000, the European Commission released a green paper titled "Towards a European Strategy on Energy Supply Security". The European Parliament and the Council emphasized the importance of reducing the risks associated with dependency. Since then, energy supply has been threatened by terrorist attacks, storms, accidents, blackouts, conflicts, and rising fuel prices. Hurricane Katrina in 2005 further complicated energy supply security, affecting not only oil production but also natural gas, transportation, refineries, and electricity infrastructure, impacting the entire energy system (Chevalier, 2006, 1).

The EU's broader resource efficiency goal, which includes the efficient use of all natural resources and the maintenance of strict environmental protection requirements, will include the implementation of the energy efficiency measures. The 2008 European Council and Parliament enacted the energy and climate change policy. This is a crucial first step toward the eventual objective of lowering global emissions by at least 50% below 1990 levels by 2050 when compared to levels of 2005 (Carvalho, 2012, 20).

Nuclear energy produces over 26% of the electricity generated in the European Union and is a low-carbon substitute for fossil fuels. But nuclear energy has grown quite contentious in the wake of the Fukushima tragedy in 2011 and the Chernobyl accident in 1986. EU regulation aims to ensure that nuclear waste is managed and disposed of securely, while Member States retain the autonomy to decide whether to incorporate nuclear power in their energy mix. EU policies are based on Articles 40–52 (investment, joint ventures and supplies) and 92–99 (nuclear single market) of the Treaty establishing the European Atomic Energy Community (European Parliament, 2024).

Since its inception, EU policy for research and technical development (RTD) has been a significant area of European legislation. A European framework program for research was added in the 1980s to further expand this policy. The majority of EU research funding in 2014 fell under the purview of Horizon 2020, a program that ensured the EU's competitiveness on the world stage and ran from 2014 to 2020. The current EU research and innovation program, Horizon Europe, was introduced in 2021 and is set to run from 2021 to 2027 (European Parliament, 2024).

[1] The Energiewende, or German energy transition, is a long-term energy and climate policy aimed at bringing Germany to a carbon-neutral energy economy by 2045. It is a large-scale economic and ecological enterprise prompted by scientific insights and ethical considerations with far-reaching economic and societal repercussions

Diversifying energy supply, integrating energy markets, and moving away from fossil fuels are among the main priorities of the EU. The importance of renewable energy in the energy policy of the European Union is vital. These practices will be discussed in the next subheading.

1.2. EU Renewable Energy Policies

It is widely acknowledged that the European Union (EU) is at the forefront of sustainable energy policies, particularly in relation to the development of renewable energy sources (Solorio, Jörgens, 2017, 48). The European Union encourages the broad use and sustainable application of renewable energy sources, such as geothermal, hydropower, wind, solar, and biofuels (IRENA, 2024). Sustainable development has emerged as a major policy in the EU in recent decades. It addresses challenges such as climate change, clean energy, sustainable transportation, sustainable production and consumption, conservation and management of natural resources, public health, social inclusion, demography and migration, and global poverty (Alvarez, 2023, 2).

Beginning with minor adjustments in the 1970s, the EU's renewable energy strategy has developed gradually over time. The single market agenda and the launch of global climate change initiatives propelled significant developments in the late 1990s. As time went on, these initiatives grew to become one of the biggest worldwide initiatives promoting the advancement of renewable energy. The evolution of the policy is a reflection of the increasing significance of renewable energy in the electricity (RES-E) and transportation (RES-T) sectors. The conflict between attempts to centralize regulation at the EU level and the aspiration of individual member states to preserve flexibility in their national support policies has been a major subject in the evolution of EU renewable energy policy. The 2009 Renewable Energy Directive (RED)[2], a significant step in unifying national policies across the EU, brought this tension to light (Solorio, Bocquillon, 2017, 23).

The European Green Deal (EGD), the EU's revised commitment to addressing climate and environmental concerns, is the most significant document outlining the EU's priorities in the field of energy and climate policy. The European Green Deal aims to keep economic growth and resource consumption apart because all regions of the EU are vulnerable to climate change-related disasters such as intense heat, floods, droughts, water shortages, melting glaciers, forest fires, windfalls, and agricultural losses. The European Green Deal, as the EU's new growth strategy, intends to change the EU into an equitable and prosperous society that lives in a modern and resource-efficient economy. Among other things, it presupposes the construction and renovation of buildings in a manner that conserves energy and resources, the preservation and restoration of ecosystems and biodiversity, the acceleration of the shift to intelligent and sustainable mobility, and the development of a wholesome, ecologically friendly food system known as "farm to fork" (Milek, Nowak, Latosinska, 2022, 2). In order to reduce net greenhouse gas emissions by at least 55% from 1990 levels by 2030, the European Commission has adopted a package of suggestions for climate, energy, transportation, and taxation policies within the EU (European Commission, 2024).

1.3. Development of Wind Energy in Europe

Following the first oil price shock in the early 1970s, interest in wind power resurfaced. This time, however, rather than mechanical energy, the primary focus was on electrical energy produced by wind power. By leveraging alternative energy technologies as a backup via the electrical grid, it became possible to supply a consistent and reliable power source (Ackermann, Söder, 2000, 317).

A turning point in the development of renewable energy was the Great Wind Revival that occurred in Europe in 1980. It signaled the comeback of wind energy as a practical and significant part of Europe's energy mix. With the help of government backing, grassroots efforts, and technological advancements, wind energy started to transition from a specialized technology to a key component of Europe's sustainable energy future (Ackermann, Söder, 2000, 318).

Once the oil embargo reignited interest in wind energy, two opposing – and frequently hostile – camps attempted to both commercialize and make wind energy viable. The fault lines in society were reflected in these camps. The current establishment's way of thought was represented by one side. In order to construct massive wind turbines, they promoted a centrally planned and managed program that worked through energy utilities or aerospace contractors (Gipe, Möllerström, 2023, 221).

The second camp, made up of a variety of businesspeople and political activists, felt that everyone should be able to contribute to the development of wind energy. They contended that building wind turbines gradually would be more appropriate for the knowledge and abilities available at the time, as well as for the small and medium-sized businesses that are most likely to be the driving force behind the growth of wind energy. They believed that wind energy should develop horizontally rather than vertically (Gipe, Möllerström, 2023, 222).

The field of wind energy technology advanced rapidly as well, reaching new heights. Before the year 2000, the first demonstration projects utilizing 2 MW wind turbines with a 74 m rotor diameter were put in place (Ackermann, Söder, 2000, 318).

Wind energy power plants underwent extensive testing and assessment in the 1990s in order to be ready to be used as a widely used technique for producing electricity for commercial use. New turbine designs with better performance and lower costs are being prompted by government and large industry assistance as well as new turbine generations (Bellarmine, Urquhart, 1996, 1748).

The "Strategy Document" released by the European Wind Energy Association (EWEA) in October 1991 sought to paint a picture of the actual opportunities presented by wind energy in the member states of the European Community for the general public, but particularly for decision-makers in the energy sector. The energy ministers of Denmark, the Netherlands, the United Kingdom, and Wind Energy Association provided funding for the

[2] On November 20, 2023, the EU/2023/2413 amending Directive came into effect. The majority of the directive's requirements must be incorporated into national law within 18 months, although other clauses pertaining to renewable energy permits have a shorter deadline of July 2024.

document's production in addition to DG XVII of the Commission of the European Communities (Sesto, Lipman, 1992, 36).

Directive 2001/77/EC on the promotion of electricity from renewable energy resources was passed by the EU in 2001. This Directive is referred to some commentators as "the single most globally significant case of legislation for wind energy." The EU Member States have developed the rudimentary national regulatory and economic systems to achieve renewable energy targets, building on the institutional framework of the Directive (Hagenbuch, 2009, 1598).

Though the Kyoto Protocol was signed in 1997, it wasn't until 2005 that it became legally obligatory after being approved by enough nations to reach the necessary number. Under the United Nations Framework Convention on Climate Change (UNFCCC), the protocol marked a historic worldwide agreement with the goal of lowering greenhouse gas (GHG) emissions in order to combat climate change. One of the main pillars of Europe's plan to reach these emissions targets swiftly became wind energy. As a viable substitute for conventional coal and natural gas power plants, it produced significant volumes of clean electricity without emitting carbon dioxide or other dangerous pollutants. Various regulations and incentive schemes were created by European governments to facilitate the expansion of the wind energy sector.

Although European Technology and Innovation Platform on Wind Energy (TPWind) was introduced in 2006 with strong policy support, the network came together to create the platform through the project UpWind[3], which was supported by the 6th EU Framework program. 43 partners from the European business and research groups were involved in the initiative. European Wind Associations (EWEA) and the European Academy of Wind Energy (EAWE) were the driving forces behind the UpWind application, and they continue to be important supporters to this day (Ricard, 2015, 12).

Since 1984, the EU has funded research and demonstration projects through framework programs. The 7th Framework Programme (FP7), running from 2007 to 2013, focused on research, technological development, and demonstration activities. It aimed to advance the Lisbon Strategy's goal of making the EU the most competitive, dynamic, and knowledge-based economy by 2010. FP7 introduced a new structure, increased budget, revised participation rules, and simplified implementation procedures, including the externalization of some administrative tasks. It comprised five specific programs: Cooperation, Ideas, People, and Capacities (European Commission, 2010). Projects to increase wind turbine efficiency, advance offshore wind energy technology, and improve wind energy system integration with the electrical grid were carried out under the auspices of these initiatives. In addition, FP7 sought to meet targets for renewable energy and boost Europe's competitiveness in the world wind energy market. Innovative innovations were developed as a result of the program's strengthening of partnerships in the field of wind energy among research institutes, universities, and industry organizations.

Adopted in 2008, the EU Strategic Energy Technology Plan (SET-Plan)[4] aims to direct funds for low-carbon technology research and innovation in Europe, thereby expediting the advancement and implementation of these technologies. In response to diminishing and dispersed funding of energy research in Europe, the Plan was considered an essential component of the EU policy portfolio. It aimed to combine limited resources to meet the energy and climate targets set in 2007 and beyond. The goal of the SET-Plan was to use extensive demonstration projects to take low-carbon technologies from concepts to the mainstream market (Skjærseth, Eikeland, 2021, 1-2).

With the goal of addressing the issues of combating climate change and securing energy supply, the Energy Act was ratified on November 26, 2008. It contains provisions pertaining to importing and storing gas. It includes provisions regarding electricity produced using sustainable resources. The Act addresses the transmission of electricity. It provides for payments to small-scale, environmentally friendly power producers. The Act includes regulations on the closing of wells and energy installations. It deals with the handling and getting rid of waste generated when nuclear plants are operating. The Act includes provisions related to petroleum-related licenses. It regulates access by third parties to pipeline improvements and oil and gas infrastructure. The Act requires reporting on topics related to energy. It outlines the obligations of the Markets Authority for Gas and Electricity. It includes provisions for reimbursements for heat produced from renewable sources. The Act regulates power and gas meters. It contains provisions for the safety of electricity. It includes regulations for the safety of hardware, software, and data concerning nuclear issues (Croner-i, 2010). In this regard, marine wind energy is a pertinent substitute since it is a clean, domestic, renewable energy source. The new generation Policy's three main goals – lowering greenhouse gas emissions, enhancing supply security, and boosting Union competitiveness – can all be significantly aided by maritime wind generation (EUR-Lex, 2012).

The implementation of instruments for collaboration between member states, such as statistical transfers, joint or coordinated support schemes, or collaborative projects, was suggested by the Renewable Energy Directive 2009/28/EC (deCastro, Salvador, 2019, 60). By 2020, 20% of Europe's energy must come from renewable sources, according to this rule. Since binding targets were established for every member state, wind energy has grown rapidly (European Parliament, 2024).

Europe's renewable energy regulations were greatly impacted by the 2008–2009 financial crisis. Following the crisis, many countries saw a significant decline in investments in wind energy projects due to deteriorating financial conditions. But to improve energy independence and fight climate change, the European Union created regulations in the wake of the crisis that encouraged investments in renewable energy, especially wind energy. In this situation, more robust financial instruments and support systems were put in place to lower obstacles for renewable energy initiatives (Blazquez, Galeotti, 2021, 1-2).

[3] Research to Improve the Design of Offshore Wind Energy Systems.

[4] Adopted in October 2023, the SET Plan modification communication will aid in harmonizing the initial strategic goals with the European Green Deal, REPowerEU, and the Green Deal Industrial Plan, which includes the Net-Zero Industry Act. It will guarantee a cohesive strategy for accomplishing the EU's decarbonization objectives, bolstering tactical net-zero energy solutions, and constructing a robust and sustainable energy future

Wind energy is one of the primary strategic energy technologies, according to the Commission. In order to bring a sizable portion of clean electricity to the European energy market and drastically lower the cost of electricity, the Commission, member states, and the wind energy industry launched the European Industrial Initiative on Wind Energy (EWI) in 2010. It is a ten-year plan for wind energy technology research and development (Radvialite, 2013, 1).

The European Commission approved the "A 2030 framework for climate and energy policies" green paper on March 27, 2013. The aim of the undertaking was to contribute creative, rigorously scientific policy analysis on specific topics to the discussion of the post-2020 energy and climate policy framework instead of tackling every issue in the package, concentrate on a technical or political "choke-point" while maintaining control and flexibility and guaranteeing timely delivery of results (Climate Strategies, 2023).

Energy presently accounts for 75% of the EU's greenhouse gas emissions, making it a crucial component in the objective of the EU becoming climate neutral by 2050. The European Commission has emphasized the necessity of decarbonizing at least six times quicker than anything accomplished internationally, raising the share of clean energy and renewable energy carriers, and enhancing energy efficiency in order to meet this goal. The SET-Plan oversees energy-related research and innovation activities in the EU. The FPs provide the majority of the financial support for these initiatives. The FP8, known as Horizon 2020 (H2020), replaced the FP7 and had a budget of EUR 79 billion. It was implemented from 2014 to 2020 (Calvo-Gallardo, Arranz, 2022, 5).

In addition to the variations in administrative and financial issues, H2020 differs from FP7 in three important areas: (1) H2020 prioritizes impact-oriented research above knowledge-oriented research; (2) it is more business-oriented than academic-oriented; and (3) it aspires to expand rather than deepen knowledge. To put it briefly, H2020 is all about connecting research to the market and society, as well as industry and innovation (Calvo-Gallardo, Arranz, 2022, 5).

As part of its commitment to building a low-carbon economy, the European Union's flagship research and innovation initiative, Horizon 2020, has given wind energy a prominent priority. Substantial financing was provided by the program to assist in the development of cutting-edge wind energy technology, such as grid integration, energy storage, and offshore wind farms. Innovation is critical to lowering prices, increasing efficiency, and boosting wind energy's sustainability, as highlighted by Horizon 2020. In order to meet the EU's targets for renewable energy and accelerate technological advancements, industry, research institutions, and public stakeholders were encouraged to collaborate on projects. These projects focused primarily on lowering greenhouse gas emissions and raising the proportion of wind energy in the energy mix.

EGD is the EU's plan for the green transition mandated by the Paris Climate Agreement. The EU's new growth plan, known as the EGD, was unveiled on December 11, 2019, by President of the European Commission Ursula von der Leyen. Its goal is to make Europe the first continent in the world to be carbon neutral by 2050, with net zero greenhouse gas emissions (European Commission, 2024). A few main goals have been the foundation of EU energy policy in recent years: environmental and climate protection, competitive economics, and energy security. Policy and economic decision-makers concurred that the European Green Deal must be implemented in this situation. The implementation of this plan ought to guarantee both rapid technical advancement and high environmental quality (Simionescu, Păuna, 2020, 3).

EGD plays a crucial role in accelerating the development of wind energy in line with the EU's goal of becoming carbon neutral by 2050. This deal increases investments in renewable energy by providing funding for wind energy projects and encourages the modernization of energy grids. Additionally, it develops strategies to boost offshore wind energy potential, with major projects planned in regions like the North Sea and the Atlantic. As the wind energy sector grows, the Green Deal aims to increase green jobs and a skilled workforce. Simultaneously, it supports the expansion of wind energy while considering environmental sustainability and biodiversity protection measures (EIPA, 2024).

2. Current Status of Germany about Offshore Wind Energy

Germany has long been interested in wind energy technologies. Today, under the new regulations, the Federal Network Agency launched its biggest offshore wind farm area tender to date in July 2023. Three North Sea zones with a combined capacity of 2,000 MW each and one 1,000 MW area in the Baltic Sea were included in the tender. The first round of bidding concluded with multiple zero-support proposals for the relevant areas, as was to be expected. In such a case, the modified Offshore Wind Act mandates a second round of bidding in which only bidders who submitted a zero-bid are permitted to take part. The bidders no longer compete to provide the least amount of funding in this round. Rather, what they bid is the price they are prepared to pay to secure the corresponding space and capacity (CMS, 2023).

According to recent data from Deutsche WindGuard[5], the offshore wind energy market in Germany is expanding significantly, with 377 MW added in the first half of 2024. With 73 more foundations built and 36 turbines starting to flow into the grid, there are now 29 offshore wind projects operational, totaling 8,858 MW of installed capacity spread among 1,602 turbines. There are two additional projects in construction right now (4coffshore, 2024).

In Germany, 29 offshore wind power farms were up and running by the middle of 2024 and installed offshore wind power capacity was approximately 8 gigawatts (GW). By the end of 2024, two further projects—Gode Wind 3 and Baltic Eagle—should be put into service. In 2023, the foundation installations for the two projects were already finished. Beginning in 2024, the turbines were installed, and many of them have already been put into service. For the Borkum Riffgrund 3 project, the foundations were

[5] Deutsche WindGuard is a German enterprise offering a wide range of wind energy-related services and knowledge. Established in 2000, the organization holds a significant position in the wind energy sector by providing an extensive array of technical and advisory services with the goal of maximising wind energy generation, guaranteeing security, and augmenting operational effectiveness.

erected toward the end of 2023, and the first turbines were put in the first half of 2024. In May 2024, OWP EnBW He Dreiht's foundation installation started. A final investment decision was taken in the spring of 2024 for the Windanker and NC 1-4 projects, in addition to these construction- related activities. By the end of June 2024, additional offshore wind energy projects had been awarded or had claimed grid connections (Wind Guard, 2024, 4).

A large offshore wind farm called Gode Wind 3 is presently being built in the North Sea off the coast of Germany. The wind farm, which is jointly owned by Ørsted and Glennmont Partners, is expected to have a 253 MW capacity. The project is anticipated to be operational in 2024, having started with a final investment decision in 2021. Twenty-three Siemens Gamesa SG 11.0-200 DD turbines, each with a rotor diameter of 200 meters and an 11 MW capacity, will make up the wind farm (NS Energy Business, 2024).

The Baltic Eagle offshore wind farm project is being built in the German state of Rügen, close to the Baltic Sea. It is a collaboration between Masdar and Iberdrola. With a 476 MW overall capacity, the wind farm should be operational by the end of 2024. When Baltic Eagle is finished, it will provide clean electricity to about 475,000 families and cut yearly CO2 emissions by almost one million tons (Baltic Wind, 2024).

With a capacity of 913 MW, Borkum Riffgrund 3, which is presently being built off the coast of Lower Saxony, Germany, will be the country's largest offshore wind farm when it is finished. This Ørsted-built offshore wind farm is noteworthy for being the first in Germany to be developed without subsidies, thanks to corporate power purchase agreements (CPPAs) with businesses like Google, Amazon, and BASF. Eighty-three Siemens Gamesa SG 11.0-200 DD turbines, each with an 11 MW capacity, will make up the wind farm. The first turbines were deployed in June 2024, after construction started in 2023. The project is expected to be fully operational by 2025 (Ocean Energy Resources, 2024).

OWP EnBW He Dreiht is an offshore wind farm that is being built in the North Sea, 110 kilometers west of Helgoland and 85 kilometers northwest of Borkum. When finished, it will have a 960 MW capacity and will be Germany's largest offshore wind farm. EnBW (Energie Baden-Württemberg AG) is developing the project, which should be operational by the end of 2025. The wind farm will be one of the first commercial installations of the advanced turbine model, Vestas V236-15.0 MW, with 64 turbines that can individually produce 15 MW of power. These turbines have massive monopile foundations that are 70 meters long, 9.2 meters in diameter, and weigh about 1,350 metric tons apiece (Maritime Executive, 2024).

As a component of their Baltic Hub strategy, Windanker is Iberdrola's third offshore wind farm project in the German Baltic Sea. The project, which is expected to cost about €800 million, is expected to start up in 2026. The 315 MW Windanker project will be made up of 21 Siemens Gamesa wind turbines, each with a 15 MW capacity. When the wind farm is fully operational, it will produce enough electricity to power roughly 315,000 households annually, which translates into a yearly reduction of about 500,000 tonnes of CO2 emissions (Offshore Wind, 2024).

The NC 1-4 project is a component of the larger North Sea cluster, an offshore wind farm situated in the North Sea of Germany. There are two primary stages to the development of the Nordseecluster: Nordseecluster A and B. Two offshore wind farms make up Nordseecluster A, which has a combined capacity of 660 MW; Nordseecluster B adds another 900 MW, bringing the total capacity to 1.6 GW. It is anticipated that these wind farms will provide 6.5 terawatt-hours of renewable energy per year. Key components of Nordseecluster A are now being built, and complete operations are anticipated by 2027 (Total Energies, 2024).

3. Future Prospects of Germany about Offshore Wind Energy

German government amended the Offshore Wind Energy Act (WindSeeG) in late 2020 with new expansion targets in an effort to raise installed power capacity. The combined capacity of offshore wind power facilities is expected to reach 20 gigawatts by 2030, and maybe reach 40 gigawatts by 2040. This will be accomplished by growing the number of tenders while also growing the power grid. To transfer energy from offshore wind farms to land, large-capacity connecting lines are required. This is another factor driving up the importance of using onshore wind, along with the increased prices and expenses associated with building offshore plants (EWE, 2024).

The expansion of offshore wind energy until 2037 is the main emphasis of a draft update to the area development plan, which was provided by the German Federal Maritime and Hydrographic Agency (BSH). With an ambitious plan to reach about 50 GW by 2035 – 10 GW more than the initial forecast – it is expected to surpass the previous legal target. In addition to meeting immediate needs, the plan creates the framework for reaching the long-term goal of 70 gigawatts by 2045. Future expansion sites have been discovered and assigned, mostly in locations close to existing shipping lanes (Review Energy, 2024).

With an installed capacity of 6.7 GW compared to 1.1 GW in the Baltic Sea, the majority of Germany's offshore wind turbines are situated in the North Sea. Considering that 14 of the 17 locations included in the Site Development Plan (Flächenentwicklungsplan) are in the North Sea, it appears that this tendency will probably continue. Technically speaking, the capacity of each individual turbine has been increasing. Existing turbines have an average capacity of roughly 5.3 MW, whereas those scheduled for commissioning by 2025 will have capacities ranging from 9.5 to 15 MW (with an average of roughly 11 MW) (Norton Rose Fulbright, 2023).

By 2035, the goal is for practically all of Germany's electricity supply to come from renewable sources in order to satisfy climate commitments and provide energy security. The German Bundestag passed extensive reforms in July 2022, relating to the EEG[6] and the WindSeeG, among other things, in order to accomplish this goal. Offshore wind energy is expected to grow faster if installation circumstances are adjusted and support measures are continuously put in place. Offshore wind turbines are expected to have an

[6] The German Renewable Energy Sources Act, or EEG (Erneuerbare-Energien-Gesetz), is a significant piece of law designed to encourage the growth of renewable energy in Germany. As part of Germany's efforts to move away from fossil fuels and nuclear energy and toward a more sustainable energy system, it was initially deployed in 2000.

installed capacity of at least 30 GW by 2030, 40 GW by 2035, and 70 GW by 2045 (Norton Rose Fulbright, 2023).

The planning of new offshore wind power projects now faces fewer regulatory roadblocks, and approval processes are become shorter and more digitalized in order to meet these objectives. Offshore wind energy bidding will undergo a significant organizational change in the future. The EEG's Section 2 simplifies the process of approving new offshore wind projects significantly. Until Germany's electricity generation is carbon neutral, this will see the construction and operation of renewable energy plants and related ancillary infrastructure declared to be in the overriding public interest and to serve public safety (Norton Rose Fulbright, 2023).

The Federal Government unveiled its national hydrogen strategy in June 2020, and offshore wind power plays a big part in it. The plan states that by 2030, 90–110 TWh of hydrogen will be required. Up to 5 GW of new green hydrogen generation capacity, including onshore and offshore energy generation, will be required within Germany to supplement imports. Offshore wind energy groups contend that in order to draw in more investment in projects, tendering volumes should be modified because the new offshore wind energy capacity is not yet represented in the offshore wind energy support auctions (Kerres, Sieler, 2020, 7).

The offshore wind energy support program has undergone multiple changes over time. In 2014, a feed-in premium took the place of the feed-in-tariff system at the federal level. Since 2017, technology-specific auctions for medium- and large-scale renewable plant projects have decided this feed-in premium instead of the law. A transition time was also included by the 2017 support scheme reform for offshore wind projects with projected commissioning dates of 2021–2025 that already had permits or were in advanced stages of approval in August 2016. A "central model" was put in place for projects that would be constructed after 2026. In the future, sites that are put up for auction to project developers will be pre-developed by the Federal Maritime Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie, or BSH) (Kerres, Sieler, 2020, 7).

By the middle of 2023, the government had set aside regions in the North Sea for the production of hydrogen offshore, paving the way for the conversion of 1 GW of offshore wind energy into hydrogen. A significant step toward creating a hydrogen economy as part of Germany's larger decarbonization objectives has been reached with this. Projects are also in progress to support the infrastructure required for the pipeline-based conveyance of green hydrogen from offshore production facilities to land (Clean Energy Wire, 2024).

Germany's offshore wind energy targets play a critical role in supporting green hydrogen production and accelerating the country's energy transformation. It is clear that offshore wind energy will continue to be important for Germany to achieve its climate neutrality goals in the coming years.

Conclusion

The EU and its member states are among the regions that take the climate crisis most seriously today. The most important document defining the EU's priorities in the area of energy and climate policy is the EGD, the EU's updated commitment to tackling climate and environmental challenges. Since all of the EU's regions are susceptible to climate change-related disasters such extreme heat, floods, droughts, water shortages, melting glaciers, forest fires, windfalls, and agricultural losses, the EGD seeks to keep economic expansion and resource consumption apart. As the EU's new growth strategy, the European Green Deal aims to transform the EU into a prosperous and just society that coexists with a cutting-edge, resource-efficient economy.

Energy now contributes 75% of greenhouse gas emissions in the EU, making it an essential part of the goal for the EU to achieve climate neutrality by 2050. In order to achieve this target, the European Commission has stressed the need to decarbonize at least six times faster than anything achieved globally, increase the share of clean energy and renewable energy carriers, and improve energy efficiency. Wind energy has been given top priority by Horizon 2020, the European Union's flagship research and innovation initiative, as part of its commitment to creating a low-carbon economy

The Renewable Energy Directive 2009/28/EC recommended the establishment of mechanisms for cooperation amongst member states, including statistical transfers, joint or coordinated support schemes, or cooperative initiatives. This regulation states that by 2020, twenty percent of Europe's energy must come from renewable sources. Since each member state was given binding targets, wind energy has increased significantly. To improve energy independence and combat climate change, the EU has given importance to renewable energy types such as wind energy. The Commission states that one of the main strategic energy technologies is wind energy.

As the EU's largest economic power, Germany is making significant investments within the framework of both the EGD and the Renewable Energy Directive. At the EU level, Germany is one of the countries that invests the most in renewable energies and especially in off shore wind energy. Most of Germany's offshore wind turbines are located in the North Sea, where their installed capacity is 6.7 GW, whereas it is 1.1 GW in the Baltic Sea. This tendency is likely to continue, given that 14 of the 17 places included in the Site Development Plan (Flechenentwicklungsplan) are located in the North Sea. In a technical sense, the capacity of every single turbine has been rising. The current turbines are expected to be activated by 2025 and have an average capacity of around 11 MW, while the existing turbines have an average capacity of approximately 5.3 MW.

In order to meet environmental targets and provide energy security, nearly all of Germany's electricity supply is expected to originate from renewable sources by 2035. To achieve this, the German Bundestag passed a number of significant reforms in July 2022, including those pertaining to the WindSeeG and the EEG. It is anticipated that offshore wind energy would increase more quickly if installation conditions are modified and ongoing support measures are implemented. By 2030, at least 30 GW of offshore wind turbines should be erected; by 2035, 40 GW; and by 2045, 70 GW.

In summary, wind energy – especially offshore wind – is essential to Europe and Germany's energy policy and serves as the cornerstone of the country's shift to a sustainable, carbon-neutral future. Germany's efforts to decarbonize its energy system depend heavily

on offshore wind power because of its unparalleled efficiency, scalability, and capacity to deliver a steady and uninterrupted electricity supply. In addition to its positive effects on the environment, offshore wind energy development contributes significantly to economic growth, job creation, and Germany's continued global leadership in renewable energy technology. Germany is demonstrating its commitment to leading the world's clean energy transition by investing in cutting-edge energy solutions including green hydrogen, infrastructure modernization, and offshore wind farms. The nation's commitment to renewable energy ensures long-term energy security and economic resilience in addition to supporting its aggressive climate ambitions. Germany is setting the stage for a future that strikes a balance between economic growth, environmental sustainability, and energy independence by adopting offshore wind energy. This will make Germany an international leader in the battle against climate change.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

The authors confirm being the sole contributor of this work and have approved it for publication.

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Conflict of interest

No potential conflict of interest was reported by the author (s)

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