Report 2022

Denmark

Photo: Caroline Brundle Bugge / Getty Images Signature, Canva.

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Denmark continues to uphold its position as a global leader within a variety of renewable energy integrations. 2022 became a record year for wind energy generation, which accounted for 53% of energy demand.

However, a modest 131 MW of new onshore wind power capacity was installed. The energy islands in Danish waters continue to advance through various site investigations, legislation requirements, and market design. The RD&D priorities reflect wind energy becoming a dominant contributor to the energy system, focusing on appropriate test facilities, system integration and Power-to-X (PtX).

Highlight(s)

- Record year where 53.4% of total power consumption was produced by wind energy.
- Increasing political ambitions for large-scale offshore wind energy in Danish waters.

Table 1. Key National Statistics 2022: Denmark

Total (net) installed wind power capacity	7.026 GW
Total offshore capacity	2.306 GW
New wind power capacity installed	0.129 GW
Decommissioned capacity (in 2022)	0.049 GW
Total electrical energy output from wind	19.002 TWh
Wind-generated electricity as percent of national electricity demand	53.4%
Average national capacity factor	31.2%
Targets	55% renewable energy by 2030 ~ 100% renewable power by 2030 Phase out coal by 2030 70% CO2 reduction by 2030 Fossil-free energy system by 2050
National wind energy R&D budget (wind + RE integraton)	264 million DKK

- Increased export of wind technology and related services.

Market Development

Targets and Policy

In accordance with the Energy Agreement of 2018, the national target is 55% renewable energy by 2030, equivalent to more than 100% renewable electricity, and to phase out coal in the energy system. Furthermore, the Danish Government created a target in 2011 to become totally independent of fossil fuels by 2050.

Progress and Operational Details

Record high production from wind and solar energy in 2022. The power production from wind and solar constituted 59.6% of total power consumption, a 12.2% increase compared to 2021. Notably, the share of wind energy increased from 43.8% in 2021 to 53.4% in 2022, despite 2021 being a much windier year. In addition, the offshore wind farm, Kriegers Flak, had its first full generation year in 2022. A contributing factor to the wind and solar record is furthermore attributed to a 3% reduction in power consumption [1].

Variable power production from wind and solar requires a broad portfolio of system services to balance the power system in the future. This includes

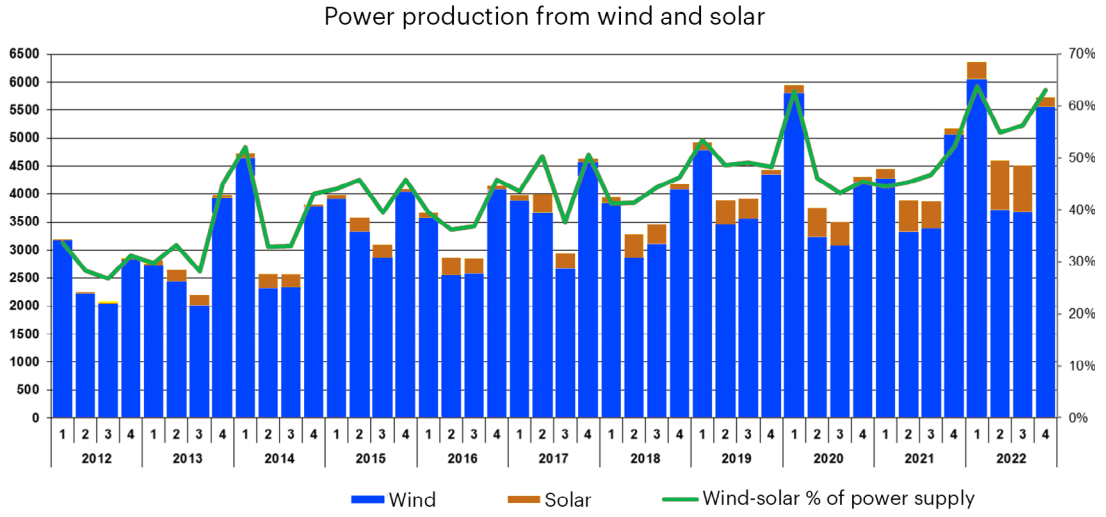

Figure 1. Source: El-månedsstatistik 2302 (Månedlig og årlig energistatistik | Energistyrelsen (ens.dk)).

capabilities in forecasting, storage/PtX, sector coupling, new service providers, etc. According to the Danish transmission system operator, Energinet, Denmark is projected to be capable of installing an additional 8 GW of new renewable capacity to the grid over the next five years. This will be possible due to reinforcement of the grid in western Denmark and the implementation of additional grid measures in progress. Furthermore, the Viking Link interconnector between Denmark and the UK expected to be commissioned in 2024 with the purpose of easing grid constraints [2].

Green power reduces the import of expensive fossil power from neighbouring countries. Between 2021 and 2022, power prices increased by more than 140%. However, a strong coupling between green power production and price meant that the record high production of wind and solar power helped to offset the increasing power prices in months with high wind and solar energy production [1].

Wind energy in 2022. Denmark installed a meagre 129 MW of wind power capacity in 2022. All of which was onshore, mainly due to uncertainties related to a new tariff structure that considers geographical differences and producer payment [3]. The new tariff came into operation in January 2023 with the purpose of making power producers account for the costs of new grid investments in a differentiated way. In areas with a production deficit, the tariff is 0.46 øre/kWh (0.0062 EUR/kWh; 0.0068 USD/kWh) and 1.06 øre/kWh (0.014 EUR/kWh; 0.016 USD/kWh) in areas with a production surplus.

Wind energy outlook 2050. The Danish Energy Agency published its analytical assumptions for the future energy system leading towards 2050, which considers the pipeline of new projects, political agreements, and technological development. Regarding onshore wind, the agency expects a substantial expansion, as well as the decommissioning and repowering of old wind turbine fleets [4]. Meanwhile, ambitious targets regarding the development of offshore wind anticipate an additional 36 GW by 2050 [5].

9 GW of offshore wind to be auctioned in 2023. The Danish Government pledged to auction 9 GW of offshore wind in 2023, which is meant to contribute to decarbonising the energy system. Furthermore, to export green fuels to the European market [3].

Advancement on the energy islands. In 2020, a political decision was made to establish an artificial island in the North Sea that will serve as a hub for offshore wind farms by supplying 3 GW of energy and a long-term expansion potential of 10 GW. In the Baltic Sea, an energy island was designated on Bornholm, where electro-technical facilities on the island serve as a hub for offshore wind farms off the coast, also supplying 3 GW of energy. The energy islands are expected to host or connect to large-scale PtX facilities. Currently, the Danish Energy Agency is preparing the procurement for the shared ownership of the island construction in the North Sea. The offshore wind farms in the North and Baltic seas will be put out to tender at a later time. Meanwhile, the national TSO, Energinet, cooperates closely with neighbouring TSOs to strengthen cross-border transmission lines. Concerning the Bornholm energy island, they are collaborating with the German, 50Hertz

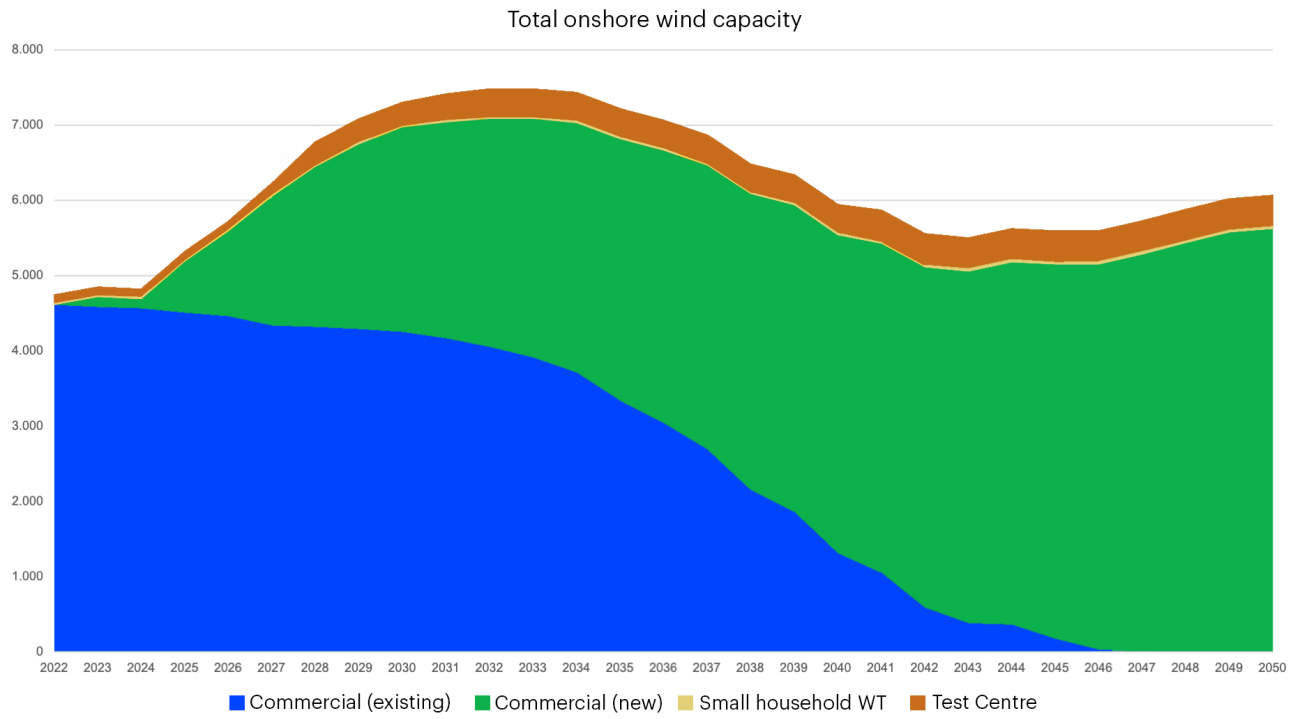

Figure 2.

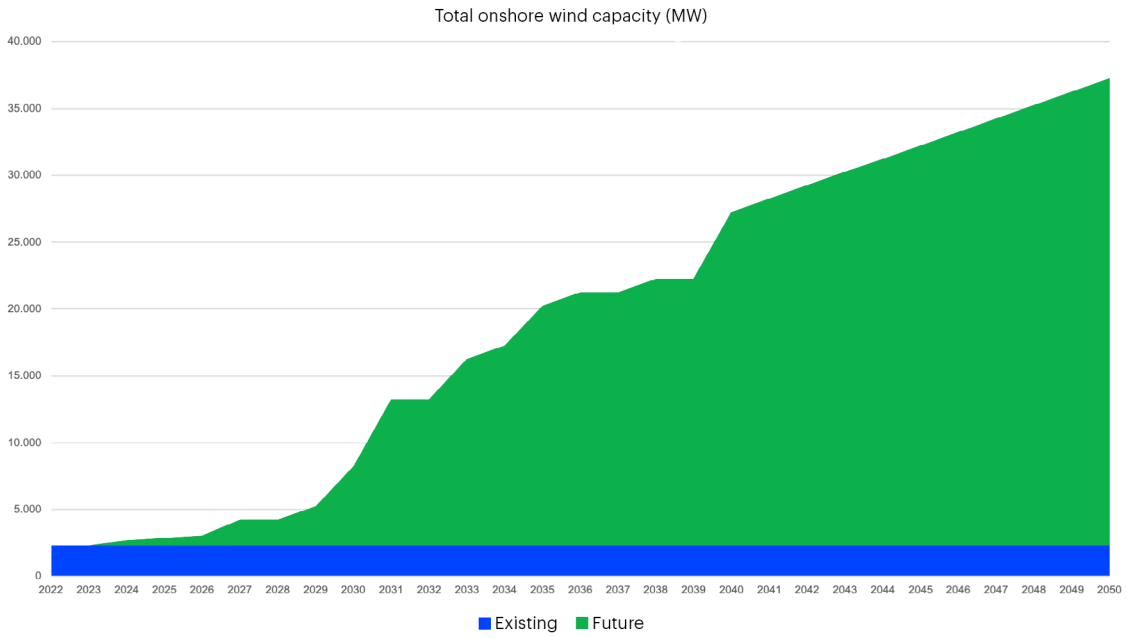

Figure 3.

and Belgian Elia regarding the North Sea offshore energy hubs.

Support scheme for renewable hydrogen approved. In February 2023, the European Commission approved the DKK 1.25 billion (167 million EUR; 184 million USD) Danish support scheme for renewable hydrogen production. The scheme supports further scaling of the production of renewable hydrogen and derivatives, such as renewables-based ammonia, methanol, and e-Kerosene, using PtX technologies. Notably, it is estimated that it can support up to 200 MW of electrolysis capacity. The aid will take the form of a direct grant for a ten-year period and will be awarded through a competitive bidding process. The tender will be open to all companies planning to construct new electrolysers in Denmark and will be finalised in 2023 [3]. The Danish Energy Agency announced the beginning of the bidding process in April 2023, which will remain open until the 1st of September 2023.

Stop and go on natural gas. The Danish government furthermore committed to reducing its dependence on natural gas by 2030, as part of its new energy package. Its purpose is to firstly, reduce dependence on Russian gas and secondly, to increase the speed of the green energy transition. However, to fulfil this goal, it temporarily relies on increasing the extraction of gas from the North Sea to ensure the security of supply. Therefore, the Danish government requested Ørsted to resume the operation of three fossil fuel plants. These include two coal plants with a total capacity of 730 MW and one oil plant of 260 MW [2].

RD&D Activities

National RD&D Priorities and Budget

The Danish RD&D funding landscape relevant to wind energy consists of The Energy Technology Development and Demonstration Programme (EUDP), administered by the Danish Energy Agency and Innovation Fund Denmark (IFD). Additionally, the Independent Research Council supports wind energy-related research. Furthermore, additional funding for wind energy RD&D, which is not accounted for in this report, is generated from private foundations as well as the industry itself.

New RD&D projects. In 2022, EUDP supported new wind and RE integration projects with DKK 264 million (35 million EUR; 38 million USD) out of DKK 498 million (66 million EUR; 71.7 million USD), adding to the portfolio of more than 90 wind energy projects [6].

MegaVind. The national strategic platform, MegaVind, is dedicated to research, innovation, testing, and demonstration. In 2020, it revised its mission to establish the foundation for the future of wind energy systems in Denmark. This public-private partnership carries a strong global position and outlook concerning four research and innovation priorities:

1. Delivering gigawatts of wind power to the green transition.
2. Upscaling and industrialisation, including enabling cost reductions.
3. Sector coupling to increase the value of wind for companies and society.
4. Sustainability for people and the natural environment [7].

MegaVind furthermore published its key recommendations for national

priorities for testing and demonstration of wind energy solutions [8].

Wind Turbine Test Centres. In December 2021, a broad majority in Parliament agreed to further develop Danish test centres with prototype wind turbines and establish additional test pads for large wind turbines. During 2022, further investigations were undertaken to identify suitable sites for a third test centre.

National Research Initiatives and Results

- **Development of low-noise and cost-effective wind farm control technology (2018-2021).** Regarding this completed project, Innovation Fund Denmark granted DKK 13.4 million (1.79 million EUR; 1.97 million USD) to the project led by DTU Wind in cooperation with Siemens Gamesa, EMD and Force Technology. Noise from wind turbines (WTs) is one of the main barriers to public acceptance and further onshore deployment of wind energy. The project therefore developed accurate noise-chain models and mitigation strategies to limit noise exposure levels from WTs. Value creation was realised through 1) the integration of the noise-chain tools into the EMD's WindPRO and Siemens' design tool, 2) recommendations for updated noise regulation standards, and 3) commercialisation of WindPRO and mitigation strategies in existing and new wind farms.

- **Control of next-generation wind turbines (2023-2026).** EUDP granted DKK 3.13 million (0.4 million EUR; 0.5 million USD) out of DKK 4.81 million (0.64 million EUR; 0.71 million USD) to this project, in which DTU Wind and Vestas develop and demonstrate a "flow-field-aware controller" for the next generation of wind-turbine control. The key innovations in the control system are 1) a hub lidar for high-fidelity wind measurements, 2) a real-time estimator of the full-field turbulence, and 3) a control algorithm that reacts to the full field. DTU will test the hub lidar using their Rotating Test Rig and implement real-time turbulence estimation, while Vestas focuses on a novel control algorithm that uses the rotor-wide turbulence field. A prototype of the control system will be demonstrated on a technologically relevant turbine with a rated power greater than 2 MW.

- **Next Generation Blade Access for Next Generation Offshore Wind Turbines - NextGenBladeAccess (2023-2025).** Towards this project, EUDP has granted DKK 10.83 million (1.45 million EUR; 1.66 million USD), or 49% of total project costs. Development of NextGenBladeAccess will be performed in a consortium that covers most downstream activities concerning the maintenance and repair of blades offshore. RWE is the owner of the offshore wind turbines and partners with the following service providers. PP Techniq A/S is responsible for the manufacture of the system and is, furthermore, the lead partner in this project. IWS Services A/S is responsible for the logistics of the system from land to the offshore wind turbine, and Muehlhan Windservice A/S operates in service and repair at the wind turbine. The development of NextGenBladeAccess is expected to reach TRL 8, where a complete prototype will be tested in realistic conditions at one of RWE`s offshore wind turbine parks, presumably at Rodsand II.

- **Offshore Energy Hubs (OEH) (2022-2026).** A grant of DKK 26 million (3.48 million EUR; 3.83 million USD) has been provided by EUDP, of the DKK 39 million (5.22 million EUR; 5.1 million USD) project led by DTU Wind in cooperation with AAU, Energinet, Ørsted, Siemens Gamesa, Energy

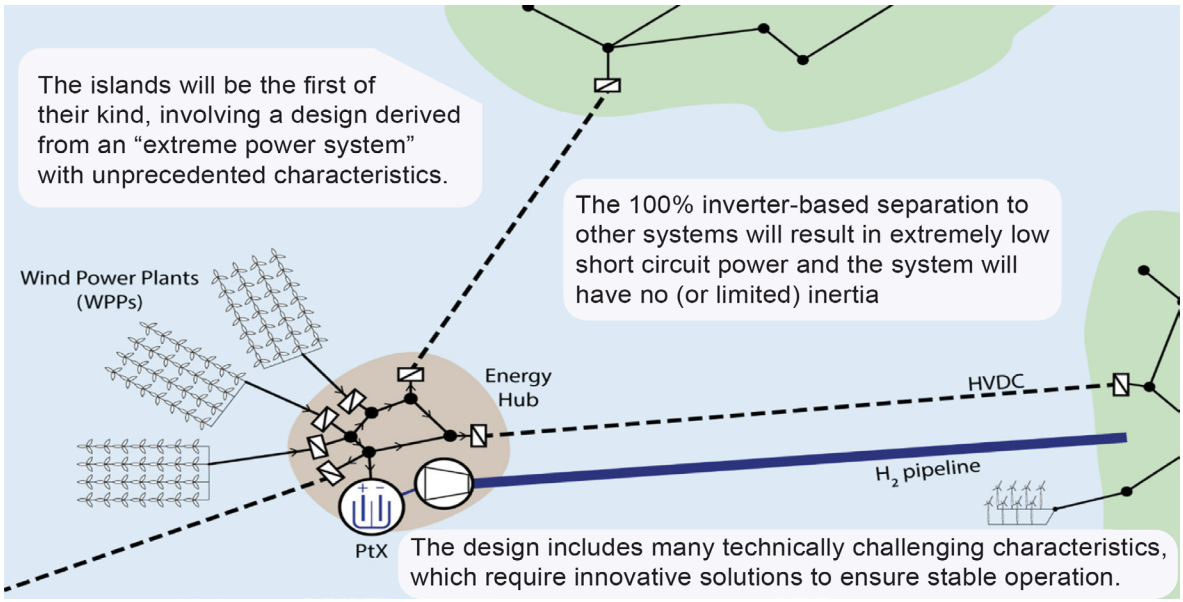

Figure 4.

Cluster Denmark, Supergrid Institute, CENERGY, and Green Hydrogen Systems. The Offshore Energy Hubs (OEH) project develops technical solutions addressing the following aspects of Energy Islands: a) Tools and control solutions for stable and resilient hub operation, b) cost-efficient design of wind power plants (WPPs), c) hub-optimised offshore Power-to-X (PtX). The value created by the OEH-solutions is both direct and indirect as the developed solutions have the potential to reduce capital costs by DKK 20 billion (2.6 billion EUR; 3 billion EUR) for an energy island of 10 GW. Most importantly, it will enable the future-proof expansion of energy islands.

Test Facilities and Demostration Projects

Test of VESTAS V236-15.0 MW prototype wind turbine produced its first kWh after being fully assembled at the Østerild National test centre for large wind turbines in Western Jutland, Denmark.

Figure 5. Vestas V236-15 MW wind turbine at Østerild Test Centre

Test Centre Høvsøre, West Jutland

The centre offers seven testing sites for international companies to test their wind turbine concepts and collect data from tests carried out on the turbines. It is possible to test and document safety, performance, and noise emission in up to 200 metres in overall turbine height.
Test Centre Høvsøre (dtu.dk)

Test Centre Østerild, West Jutland

This centre offers state-of-the-art facilities to test up to nine wind turbines. Of which, Vestas owns two, Siemens Gamesa two, and DTU Wind Energy owns the remaining five test sites. It is possible to test turbines up to 330 metres in five of the test sites and up to 250 metres, at the remaining sites. Additionally, an investigation to increase the max height to 400 metres is underway.
Test Centre Østerild (dtu.dk)

The Large-Scale Facility , DTU Risø Campus	The facility consists of a 1,560 square metre test hall with three test stands capable of testing 45 metre, 25 metre and 15 metre blades or other slender structures. Large Scale Facility - DTU Wind and Energy Systems
Poul la Cour Wind Tunnel, DTU Risø Campus	The Poul la Cour Tunnel is a wind tunnel of the closed-return type. The fan is driven by a 2.4 MW motor, giving a volume flow of up to 630 cubic metres per second. This corresponds to a maximum test section velocity of about 105 m/s or 378 km/h. Poul la Cour Wind Tunnel - DTU Wind and Energy Systems
Composite Laboratories, DTU Risø Campus	Composite lab for R&D within hybrid processing techniques, preparation of test specimens, accredited mechanical testing to meet industrial standards, X-ray computed tomography, electron microscopy, plasma treatment and surface chemistry, sensor instrumentation, and signal analysis. Material Laboratories - DTU Wind and Energy Systems
The research wind turbine V52 DTU Risø Campus	The research wind turbine is a variable speed-pitch adjusted wind turbine and works as the main part of the large modern megawatt wind turbines. The research wind turbine V52 - DTU Wind and Energy Systems
WindScanner	Windscanner.dk was established in 2010 to provide the European wind energy research community and industry with remote sensing based wind scanners. This has the ability to map the entire 3D wind field around today's substantial wind turbines, wind farms, bridges, buildings, forests, and mountains. WindScanner - DTU Wind and Energy Systems
AC/DC Wind Power Laboratory	A converter-based laboratory aimed at investigating power electronic controls and controller interactions in low-inertia systems. It consists of four 10 kW custom-built converters. Two of them are 2-level converters, and two are MMC (modular, multi-level converters), covering the main converter technologies used today.
The Hybrid Wind Power Plant Facility	The Hybrid Wind Power Plant Facility at DTU Risø Campus consists of a small (2 x 225 kW) wind power plant which is connected to the grid, as well as storage technologies, and a small (~200 kW) solar PV plant. Two 225 kW pitch-controlled wind turbines are retrofitted with a power converter and an open research controller supplied by an industry partner with experience in wind turbine retrofits. It also includes a switchboard and a Controllable Grid Interface (CGI). It is part of The National Energy System Transition Facilities (NEST), a national network of the DTU Risø facilities, an electrofuel laboratory in Foulum, a PtW laboratory, and a microgrid test laboratory at AAU.
Lindø Offshore Renewables Center (LORC)	Lindø Nacelle Testing is located in two adjacent buildings. The 14 MW and 16 MW test facilities are located in a 3,500 square metre test hall, and the larger 25 MW test facility is located in a 2,250 square metre test hall. https://www.lorc.dk/test-facilities

Collaborative Research

The Danish Energy Agency supports Danish companies, universities, and research institutions directly or via international cooperation schemes when participating in international projects. This includes the financial support for participating in the IEA TCPs and indirectly by means of common calls in the EU (ERA-net scheme) and Nordic Energy Research. Denmark participates in most of the IEA Wind TCP Tasks.

Impact of Wind Energy

Environmental Impact

Strategic screening of offshore wind potential (2022-2025). The Danish Energy Agency has allocated resources for a strategic environmental screening of offshore wind in Danish waters between 2022 and 2025. The aim is to collect the necessary environmental data, including the cumulative impacts of offshore wind energy, and to support the long-term planning and decision-making of large scale offshore wind in Denmark. The project will map the areas potentially vulnerable to large-scale offshore wind. As part of the screening, the Danish Energy Agency will collaborate with The Geological Survey of Denmark and Greenland (GEUS) to make a geological mapping of the Danish seabed. This project will be decisive for assessing the optimal location of offshore wind turbines. Furthermore, the engineering consultancy company NIRAS, Aarhus University, and DTU Wind will provide technical assistance and advice concerning the strategic environmental screening of offshore wind potential.

Economic Benefits and Industry Development

The total revenue of the wind energy industry was DKK 128.5 billion (17.2 billion EUR; 18.8 billion USD) in 2020. It is distributed between utilities of DKK 13.4 billion (1.79 billion EUR; 1.97 billion USD) and DKK 115 billion (15.4 billion EUR; 16.87 billion USD) by the turbine industry [9]. The revenue per man-year in the turbine industry is DKK 3.8 million (509 million EUR; 561 million USD).

Job creation. The sector employed around 32,721 full-time equivalents in 2020 [10]. Thereby, approximately 2.3% of the Danish private sector workforce work in the wind energy industry. However, the sector indirectly creates an additional 60,000 full-time equivalents due to indirect employment and consumption effects, constituting a total of 90,500 full-time jobs. In addition, the sector contributed DKK 91 billion (12.2 billion EUR; 13.35 billion EUS) to the GNP, equivalent to 4% of the total GNP of DKK 2,324 billion (311.4 billion EUR; 340.9 billion USD) in 2020. An analysis of the job creation in the offshore wind sector in Denmark has highlighted the need for political support and favourable framework conditions to foster further industry development. This encompasses factors such as ensuring sufficient harbour capacity, adaptation of local roads and access to a skilled work force without local content requirements [11].

Export. In 2020, the export of Danish energy technology increased slightly to DKK 106.2 billion (14.2 billion EUR; 15.6 billion USD), of which wind technology and its related services constituted 43%. Specifically for wind energy technologies, the export in 2022 decreased by 6.8% to DKK 45.9 billion (6.16 billion EUR; 6.74 billion USD), where wind technology comprised DKK 39.9 billion (5.35 billion EUR; 5.71 billion USD) and its related services, DKK 7 billion (1 billion EUR; 1 billion USD) [12]. Additionally, export increased in comparison to other European countries by 33.7%. The top five export countries were Germany (14.3%), the Netherlands (11.5%, UK (8.3%), France (7.9%) and USA (7%).

Next Term

In April 2023 in Ostend, Belgium, nine Heads of State & Government and the President of the EU Commission agreed to new commitments on the expansion of offshore wind in the North Sea. This was a follow-up on last year's summit between Belgium, Denmark, Germany, and the Netherlands, in Esbjerg. This time, these nations were joined by France, Ireland, Luxembourg, Norway, and the UK. They agreed to joint targets for offshore wind totalling 120 GW by 2030 and 300 GW by 2050 in the North Sea, which currently stands at 30 GW. Furthermore, to expand the development of the offshore wind grid for the future.

Additionally in April 2023, the government presented a plan to reserve 30% of sea area for wind turbines. This initiative makes it possible for developers to build more turbines per square metre of sea area than before, commonly referred to as over-planting.

In May 2023, the Danish Energy Agency announced its plan to tender 9 GW of offshore wind projects that are set to be operational by 2030. This includes the completion of the Bornholm Energy Island. As part of the tendering, companies have the ability to bid in order to build more capacity on the sites than the agency is planning, which means the full potential of the sites is 14 GW.

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