Report 2021

Denmark

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Denmark continues to be a global leader in variable renewable integration. Due to a poor wind year, wind-generated electricity fell to 44% but is expected to increase significantly in the years to come.

The energy islands in the Danish waters are advancing with various site investigations, necessary legislation, and market design. R,D&D priorities reflect wind energy being a dominant part of the energy system, focusing on appropriate test facilities, system integration, power-to-x (PtX), and social perception.

Highlight(s)

- Thor 1 GW offshore wind power plant auctioned.
- Denmark, Belgium, and Germany will connect with sea cables via new energy islands, serving as transmission hubs for offshore wind farms.

Table 1. Key National Statistics 2021: Denmark

Total (net) installed wind power capacity	6.995 GW
Total offshore capacity	2.306 GW
New wind power capacity installed	0.754 GW
Decommissioned capacity (in 2021)	0.026 GW
Total electrical energy output from wind	16.082 TWh
Wind-generated electricity as percent of national electricity demand	43.8%
Average national capacity factor	45.3%
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	191 million DKK

Market Development

Targets and Policy

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

Progress and Operational Details

Developments in a number of wind turbines and capacity. Figures 1 and 2 show Denmark's wind power capacity and the number of turbines since 1977. In 2021, the net installed capacity was almost 7,000 MW, of which offshore wind accounts for 2,300 MW. 2021 was a historically poor wind year with 10% fewer wind resources than usual. The wind-generated electricity, therefore, was 43.8% of the power production. It would, however, have been 3.5% higher if the production from wind turbines had not been curtailed due to congestion in the German grid [1].

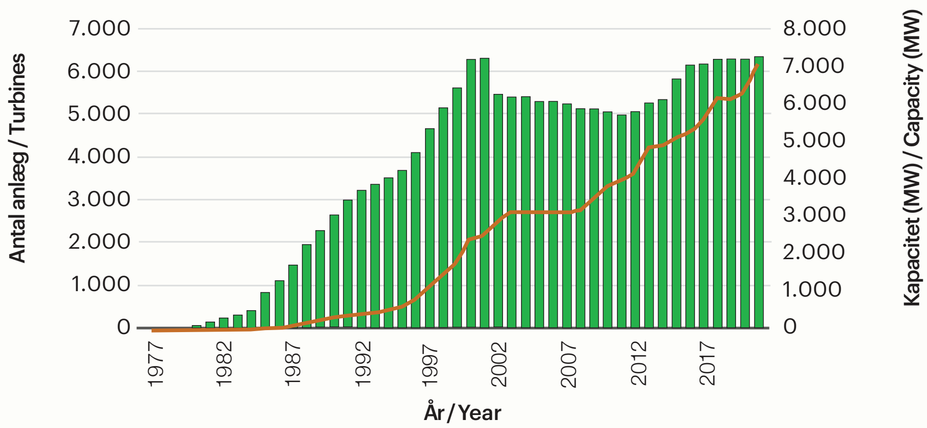

Figure 1. Tilvækst i anlæg og kapacitet / Growth in number of turbines and capacity

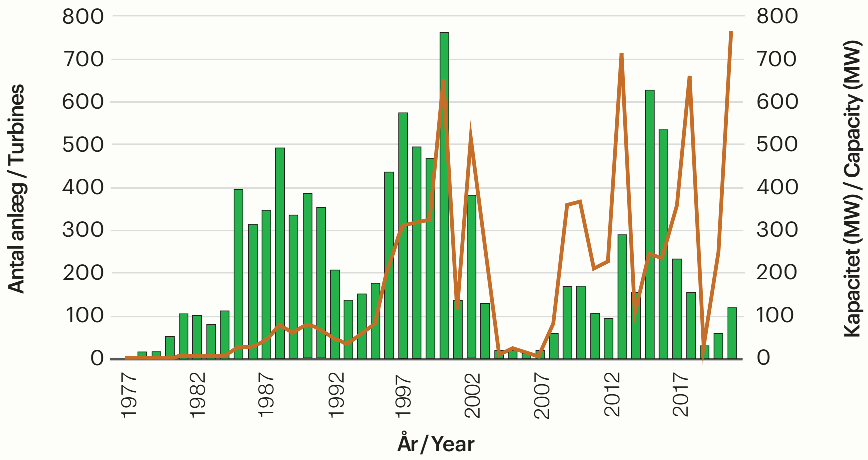

Figure 2. Årlig tilvækst i anlæg og kapacitet / annual growth in number of turbines and capacity

The offshore wind farm Thor. RWE has secured a 30-year concession for the 1 GW Thor offshore wind farm through a lottery system. The Danish Energy Agency had to draw lots to choose a winner after multiple bidders offered the minimum price (DKK 0.1/MWh/$ 0.01/MWh) for a two-sided Contract for Difference. When the market price rises above the CfD strike price (almost zero), RWE will have to pay the difference to the Danish government. This will be done until the cap of DKK 2.8 billion ($ 0.43 bn.) are paid back to the government. Afterward, the generator will only make money on selling power at market conditions with the government backing up during negative prices.

Advancing on the energy islands. In June 2020, it was politically decided to establish an artificial island in the North Sea that will serve as a hub for offshore wind farms supplying 3 GW of energy, with a long-term expansion potential of 10 GW. The energy island in the Baltic Sea will be Bornholm, where electro-technical facilities on the island will serve as a hub for offshore wind farms off the coast supplying 2 GW of energy. The energy islands are expected to host or be connected to large-scale PtX facilities. The Danish Energy Agency is preparing a procurement for the shared ownership of the island construction in the North Sea. The 5 GW of offshore wind farms in the North and Baltic seas will be put out to tender at a later time. In relation to the tendering of the energy islands, the Danish TSO Energinet has the task of conducting preliminary site investigations on the seabed, marine traffic, marine mammals, fish stocks, bird life, etc. [2]. The construction of the energy islands (wind farms, power cables on the seabed, electrical installations, etc.) is subject to the Danish Environmental Assessment Act. The actual artificial island in the North Sea will also have its construction act.

Expanded offshore wind zone. In October 2021, the Ministry expanded the scope for an offshore wind feasibility study near the island of Bornholm from 2 GW to 3 GW. Energinet started in June 2021 a feasibility study exploring conditions for 2 GW offshore Bornholm and already has ships in the area to examine seabed and environmental conditions in the area. The extended feasibility study includes options for cable connections between the energy island hub on Bornholm and offshore wind farms, and export cables to Zealand, including Copenhagen and interconnectors.

Agreement on offshore connections. Denmark, Belgium, and Germany signed cooperation agreements in November 2021 to connect their offshore electricity grids with subsea cables, including via new energy islands, which will serve as transmission hubs for offshore wind farms. Danish TSO Energinet and Belgium TSO ELIA will build the Triton Link interconnector between the Danish energy island in the North Sea and Belgium. Energinet will also work with German TSO 50Hertz (owned by ELIA Group) to connect the Danish energy island Bornholm in the Baltic Sea and Germany [3].

Power-to-X strategy. The Danish Government presented a proposal for a new strategy to promote and navigate the future development of Power-to-X (PtX) projects in Denmark. The Danish PtX strategy aims at reducing CO2 emissions, balancing the Danish power system, and providing export opportunities for green fuels and PtX technology. The government target some 4-6 GW of electrolyze capacity by 2030 [1].

Matters Affecting Growth and Work to Remove Barriers

IThe market price for wind power was in 2021 four times higher than in 2020, with an average ~568 DKK/

MWh ($ 86.9/MWh). The relative value of wind power was likewise higher in 2021 due to high demand, and in the last quarter also high prices and relatively fine wind [4].

Absolute and relative wind weighed spot prices in 2021

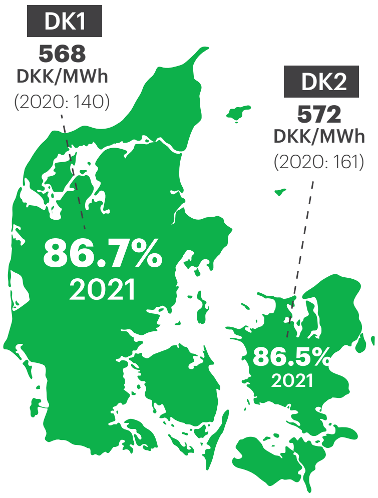

Figure 3

As an integrated part of the reform proposal in April 2022, the Danish Government proposes to improve the planning and regulation of renewable energy projects to overcome administrative barriers. This is in line with the EU Commission's effort to change the current regulation to balance climate, environmental, and energy security concerns adequately.

R,D&D Activities

National R,D&D Priorities and Budget

The Danish R,D&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). In addition, the Independent Research Council supports wind energy-related research. Further, private foundations and the industry itself finance wind energy R,D&D, which is not accounted for here.

New R,D&D projects. In 2020, EUDP and IFD supported 21 new projects with DKK 191 million ($ 29.2 million) out of DKK 846 million (129.4 million), adding to the portfolio of 74 wind energy projects [5]. As wind energy plays a key role in the overall energy system, other research areas such as intelligent grids & systems and hydrogen are also important to integrate renewable energy systems. These areas received DKK 673 million ($ 103 million), respectively DKK 376 million ($ 57.3 million).

MegaVind. The national strategic platform for research, innovation, test, and demonstration, Megavind revised its mission in 2020 to establish the foundation for the future of wind energy systems in Denmark. This revitalised public-private partnership is based on a strong global position and outlook and outlines four research and innovation priorities: 1) Delivering gigawatts of wind power to the green transition; 2) Upscaling and industrialisation, enabling cost reductions; 3) Sector coupling to increase the value of wind for companies and society; 4) Sustainability for people and the natural environment [6]. MegaVind has also published its key recommendations on the national priorities for test and demonstration of wind energy solutions, for example, a minimum of total of 20 test pads for prototype testing of turbines with a height limitation of up to 400 meters. Also, various component testing of blades, blade bearings, and nacelles were included with a call for competence building within measurement, testing, and verification [7].
Wind Turbine Test Centers. In December 2021, a broad majority in Parliament agreed to further develop the Danish test centers for prototype wind turbines and establish more test pads for large wind turbines. Investigations are undertaken to identify suitable sites for such a third test center.

National Research Initiatives and Results

- Blade Degrade Forecast (BDF) completed (2019-2022). Innovation fund Denmark granted DKK 5 million ($0.76 million) to the project with a total budget of DKK 7 million ($ 1.07 million). The project developed a blade defect forecast tool for seasonal repair prediction based on environment parameters at high temporal and spatial scales for 10-15 years ahead. Key environmental parameters were used in forecasting operational costs in the coming repair season for blades in operation and for site-specific design requirements. The BDF project was coordinated by Wind Power Lab. DTU Wind Energy and DMI were partners [8].

- **BLATIQUE-2.** 2021-2025. EUDP granted DKK 32.9 million ($ 5.03 million) to the project with a total budget of DKK 64.20 million ($ 9.82 million). The objective of BLATIGUE-2 is to develop fast and efficient fatigue testing methods for large wind turbine blades, develop smart equipment to excite the blades under such tests, and increase blade testing value through digitalization, eventually transforming the state-of-the-art technologies into turn-key solutions for market entry. The project will further improve multi-axial fatigue test methods and develop a suite of user-friendly tools that make fatigue exciters smarter by integrating hardware and software. Methods to dramatically reduce the fatigue test time of large blades will be developed through testing blade segments. Utilising digital image correlation, drone technology, and computer-vison based image analysis techniques, non-contact measurement and inspection systems will be designed to reduce the current labor-intensive and time-consuming industrial paradigms during the blade fatigue test. DTU Wind (lead) together with a.o. LM, Ørsted and DNV [9].

- **Flexible Offshore Drone.** 2022-2024. EUDP granted DKK 7.53 million ($ 1.15 million) to the project with a total budget of DKK 9.94 million ($ 1.52 million). Project partners are Upteko ApS (lead), Esvagt, Siemens, Energy Cluster Denmark, and University of Southern Denmark.

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The project aims at introducing new service technologies to offshore wind. This includes fully autonomous wind turbine inspection and package deliveries using drones and fixed charging stations on offshore service vessels. The project introduces an unseen level of autonomy and speed that will optimise the O&M cost of servicing offshore wind turbines, reduce downtime, increase the weather window, increase annual energy production, and reduce CO2 emissions [10].

- **Non Destructive Testing (NDT) inspections and analysis of wind turbine blades on operational wind turbines.** Innovation Fund Denmark granted DKK 16.9 million ($ 2.59 million) to the project with a total budget of DKK 25.4 million ($ 3.89 million). The project aims to combine Robotics' automated, remote-controlled wind turbine blade repair robot with on-site blade inspection based on automated ultrasonics currently deployed by FORCE Technology under factory conditions and to use DTU's knowledge of blade failures in composite materials to predict damage growth using fracture mechanics models [11].

- **Predicting wind turbine stability in general inflow PRESTIGE.** The Innovation Fund Denmark granted DKK 9.7 million ($ 1.48 million) to the project with a total budget of DKK 13.2 million $ 2.02 million). Modern wind turbines can experience destructive fluid-induced vibrations. Cost reduction drives the development toward increasing blade length and flexibility, increasing the risk for such vibrations. The project implements a new level of physics resolving models at three industry partners, capable of predicting these instabilities during the design phase, and will lower the cost for component replacement, and enlarge service and installation periods without the risk of aeroelastic fluctuations. Partners: DTU, Aalborg University, VESTAS Wind Power Systems A/S, Siemens Gamesa Renewable Energy A/S, LM Wind Power A/S [12].

- **Controversies in the green transition: The case of wind turbine sound and its politicisation (Co-Green).** The Independent Research Council of Denmark granted DKK 6 million ($ 0.92 million) to the project led by DTU Wind. In CO-GREEN, the researchers use the sound from wind turbines, which is commonly referred to as problematic 'wind turbine noise,' as an exemplary case to examine how a technical understanding of sound ignores all the aspects that cannot be measured, but which nonetheless creates uncertainty and controversy. The project investigates how wind turbine sound is understood and the various types of expertise that try to explain it. This deeper understanding of sound is used to examine how sound from wind turbines is often politicised and problematised in wind power deployment and sometimes leads to controversy and delayed projects. The project also uses innovative communication processes to create fertile ground for better involvement of citizens in the green transition [13].

Test Facilities and Demonstration Projects

The National Energy System Transition Facilities (NEST) is an interconnected network of a distributed energy system and a hybrid wind turbine at DTU Risø Campus, an electrofuel laboratory in Foulum, a PtW laboratory, and a microgrid test laboratory at AAU. The DKK 100 million ($ 15.3 million) network proposal is one of 16 prioritised research infrastructure projects included in the national roadmap for research infrastructure 2020 [14].

Test Centre Høvsøre, West Jutland	*It 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, the turbine's performance, and noise emission up to 200 meters in overall turbine height.* https://wind.dtu.dk/facilities/hoevsoere
Test Centre Østerild, West Jutland	*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 the remaining five. Five test sites It is possible to test turbines up to 330 meters in five of the test sites and for the remaining up to 250 m. It is being investigated how to increase the max height to 400 meters.* https://wind.dtu.dk/facilities/oesterild
The Large-Scale Facility , DTU Risø Campus	*The facility consists of a 1560 square metre test hall with three test stands capable of testing 45 m, 25 m and 15 m blades or other slender structures.* https://wind.dtu.dk/facilities/large-scale-facility
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 meters per second, corresponding to a maximum test section velocity of about 105 m/s or 378 km/h.* https://wind.dtu.dk/facilities/poul-la-cour-wind-tunnel
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.* https://wind.dtu.dk/facilities/material_testing

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.* https://wind.dtu.dk/facilities/the-research-wind-turbine-v52
WindScanner	*Windscanner.dk was established in 2010 to provide the European wind energy research community and industry with remote sensing-based wind scanners, able to map the entire 3D wind fields around today's substantial wind turbines, wind farms, bridges, buildings, forests, and mountains.* https://wind.dtu.dk/facilities/windscanner
AC/DC Wind Power Labatory	*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 together with 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).*
Lindø Offshore Renewables Center (LORC)	*Lindø Nacelle Testing is located in two adjacent buildings. The 14MW and 16MW test facilities are located in a 3,500 square meter test hall, and the larger 25 MW test facility is located in a 2,250 square meter test hall.* https://www.lorc.dk/test-facilities

Export. The COVID-19 pandemic and the lockdown of societies continued to impact the Danish export of energy technologies and services in 2021. For wind energy technologies, the export in 2021 increased just 0.5% to DKK 42.6 billion ($ 6.52 bn) and thereby far from the ex-ante COVID-19 level with DKK 52.6 billion ($ 8.05 bn) in 2019 [18].

Floating offshore wind is in rapid development, and at present, two Danish companies are active in the development, Stiesdal Offshore Technologies, and Floating Power Plant. Stiesdal has developed the Tetra technology, a fully industrialised manufacturing concept. In 2021, a first spar-configuration demonstrator with a 3.6 MW WT was installed at a 200-meter water depth at the METCentre test site off the coast of Norway [19].

Next Term

Due to the war in Ukraine and the energy crisis, the Danish Government presented in April 2022 further initiatives to become independent of Russian oil and gas [20]. It aims at tendering additional 1-4 GW offshore wind in 2030 and looks into the potential of 35 GW offshore wind in the North Sea. It will strengthen regional and European cooperation in the North Sea and the Baltic Sea regarding the supply of green energy to Europe. Included is also the preparation of new energy islands in the Danish waters. Another target is to quadruple the total solar and onshore wind production in 2030. A comprehensive proposal for green power will be presented (and negotiated) mid 2022.

The Government has also presented its proposal for a differentiated CO_2 tax on the industrial sector to cut 3.7 million tons of emissions by 2030, contributing significantly to reaching the 70% CO_2 reduction in 2030.

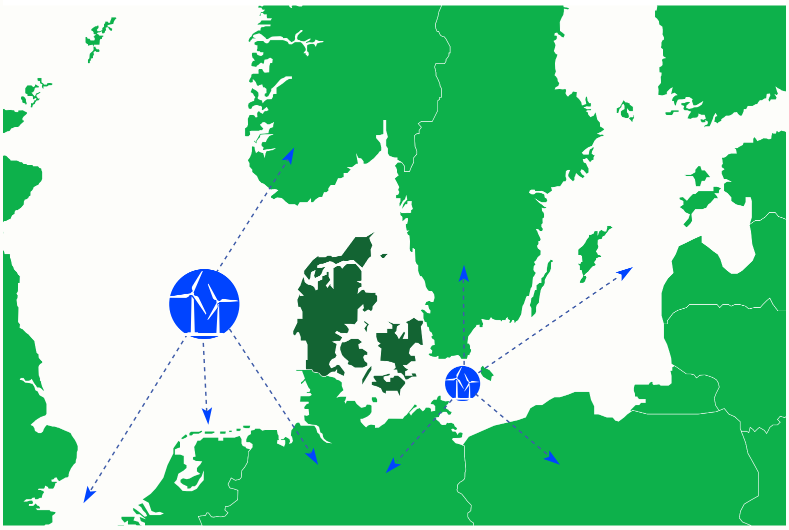

Figure 4

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