

DENMARK

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The wind power capacity in Denmark has been stable around 6 GW for nearly four years. Installed total wind power capacity increased by 220 MW onshore capacity and no new offshore capacity in 2020. This brings Denmark's total capacity to 6.311 GW of which 1.7 GW is offshore. Although the Covid-19 pandemic caused a decrease in the domestic energy consumption in 2020, it has not affected the wind deployment or R&D much.

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Wind-generated electricity met 48.0% of the domestic electricity supply in 2020 compared to 47.2% in 2019. This is still by far the highest share globally, and the share could have reached a new record of around 51% if the production from wind turbines had not been curtailed. The high amount of special down-regulation is a sign that there

TABLE 1. KEY NATIONAL STATISTICS 2020: DENMARK

Total (net) installed wind power capacity*	6.218 GW
Total offshore capacity	1.701 GW
New wind power capacity installed	0.220 GW
Decommissioned capacity (in 2020)	0.061 GW
Total electrical energy output from wind	16.308 TWh
Wind-generated electricity as percent of national electricity demand	46.9%
Average national capacity factor**	30.4%
Target	55% renewable energy by 2030 100% renewable energy in 2050
National wind energy R&D budget	113.188 mill. DKK, 15.167 mill. EUR, 18.563 mill. USD

* Installed wind power capacity: Use nameplate power ratings of the installed wind turbines.

** Average national capacity calculation: Only include turbines in operation the whole year: (MWh production/8,760 hrs) / MW installed capacity. MWh total electrical production from wind turbines operating January 1 through December 31 divided by 8,760 hrs divided by the total installed wind capacity (in MW) at the beginning of the year. [You can also use an estimate based on the average installed capacity during the year: (installed 1 Jan + installed 31 Dec)/2. But in that case, state that this is how the estimate is calculated.]

are continuing capacity problems in the electricity grid in Germany, and that there is a lack of flexible electricity consumption in Denmark, which can utilize renewable energy when it is available.

The total production from the country's wind turbines in 2020 was a national record of 16.35 TWh, which is an increase compared to 16.15 TWh in 2019 [1]. The wind energy index in 2020 was 103.4 compared to 95% in 2019, 90% in 2018, and 102% in 2017.

Market development

Targets and policy

In accordance with the Energy Agreement published on the 29 June 2018 and supported by all political parties in the Danish Parliament, the Danish target by 2030

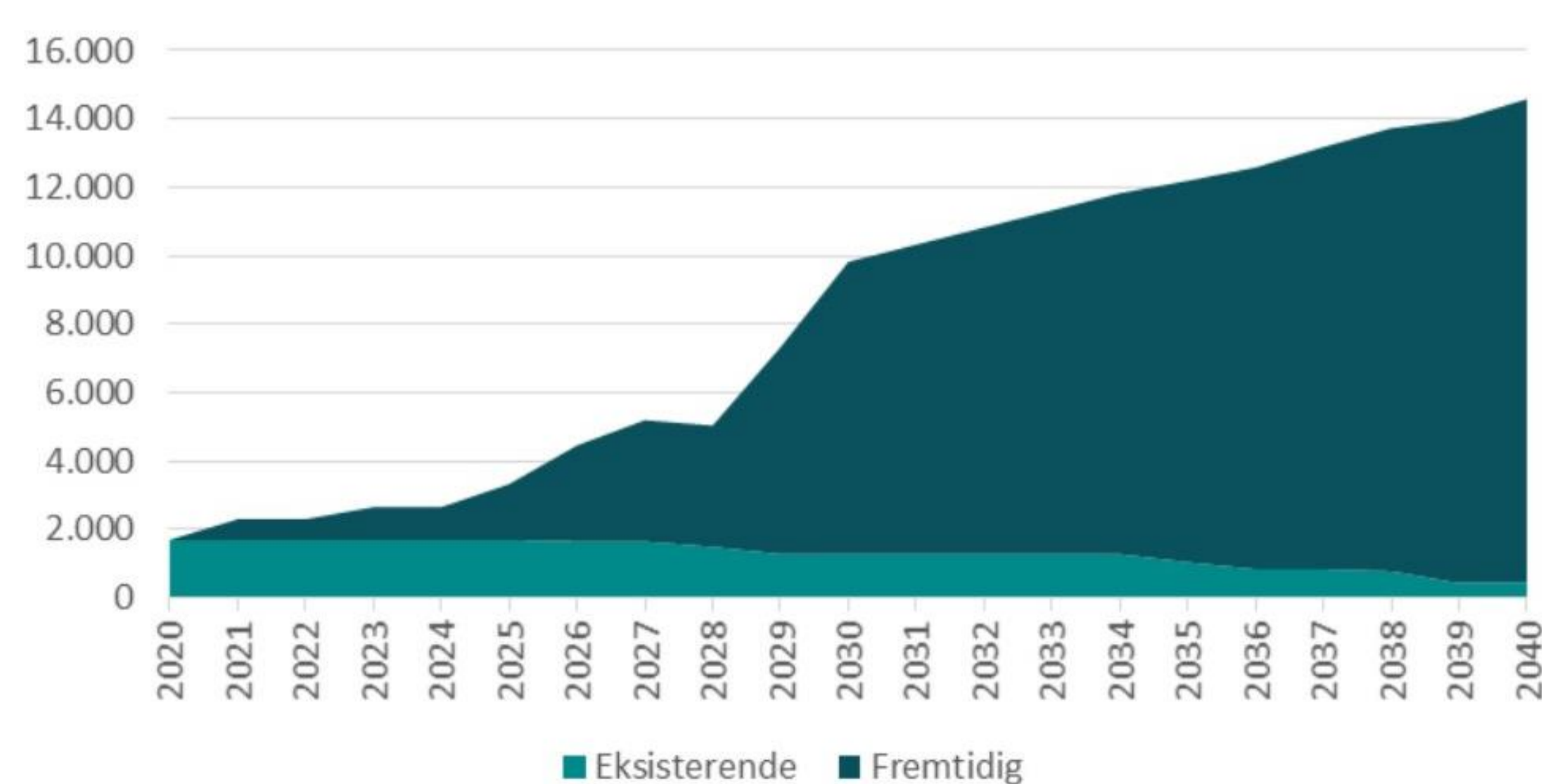


FIGURE 1. TOTAL DANISH OFFSHORE CAPACITY UP TO 2040 [2]

still is that 55% of the nation's energy needs are met by renewable energy, mainly wind and solar.

The Danish Energy Agency (DEA) published the annual analytical assumptions for the Danish electricity and gas system up to 2040. The anticipated trend for wind power is depicted in Figure 1 and 2.

World's first energy islands

With the political climate agreement of 22 June 2020, it was decided to initiate the work of realizing two energy islands, and in November 2020, the Minister of Climate, Energy and Utilities decided to reserve the gross areas in the North Sea and the Baltic Sea for the world's first energy islands [2]. The energy islands will be hubs that can create a better connection between energy from offshore wind and the energy systems in the region around the two seas.

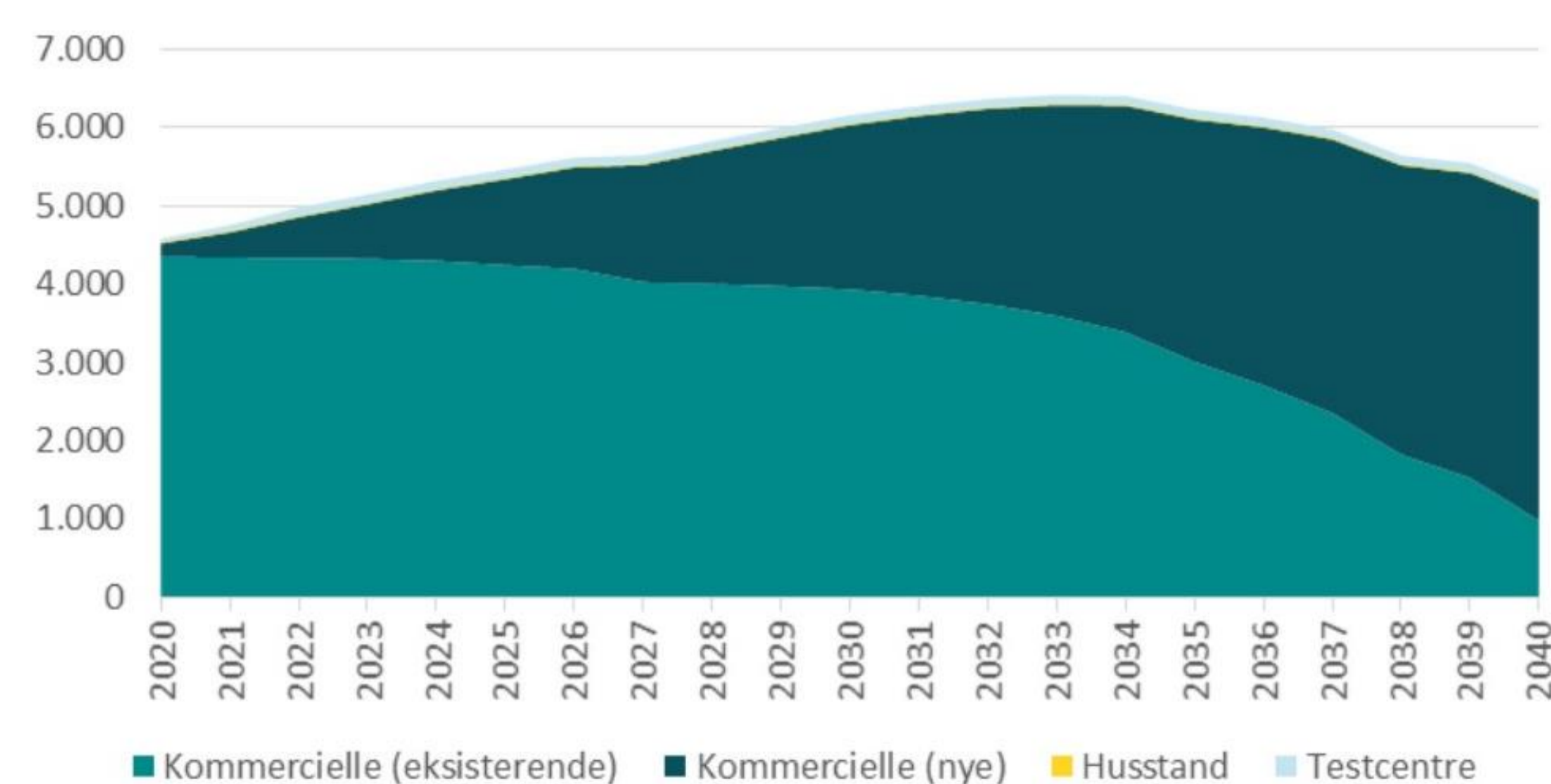


FIGURE 2. TOTAL DANISH ONSHORE CAPACITY UP TO 2040 [2]

In December 2020, the Danish Climate Minister, Dan Jørgensen, signed declarations on cooperation on energy islands with ministers in Germany and the Netherlands [3]. The declarations are an important step towards fulfilling the political wish that the energy islands should be connected to countries other than Denmark.

German 50Hertz and Danish Energinet inaugurate the world’s first hybrid interconnector

In October 2020, the German 50Hertz and the Danish system operator Energinet inaugurated the world’s first hybrid offshore interconnector, integrating both German and Danish offshore wind farms. The grid connections of wind farms Baltic 1 and Baltic 2 (Germany) as well as the grid connection to wind farm Kriegers Flak (Denmark) that is currently under construction, are also used as an interconnector. Two submarine cables of only 25 km in length with a capacity of 200 megawatts (MW) each, laid between the offshore substations of Baltic 2 and Kriegers Flak, bringing both grid connection systems together. The Combined Grid solution (CGS) connects two offshore substations in the Baltic Sea to each other as well as to the existing onshore connections of the offshore wind farms. As a result, the CGS can bring offshore wind power to Denmark or Germany and can be used for cross-border energy trading [4].

Progress and operational details

2020 was a year in which the German neighbours to a much greater extent than before paid Danish electricity producers—including many wind turbine owners—to periodically reduce production. The German electricity grid has not been expanded sufficiently in line with the installation of large amounts of wind and solar. The green power from Denmark and northern Germany cannot reach consumers in southern Germany, as

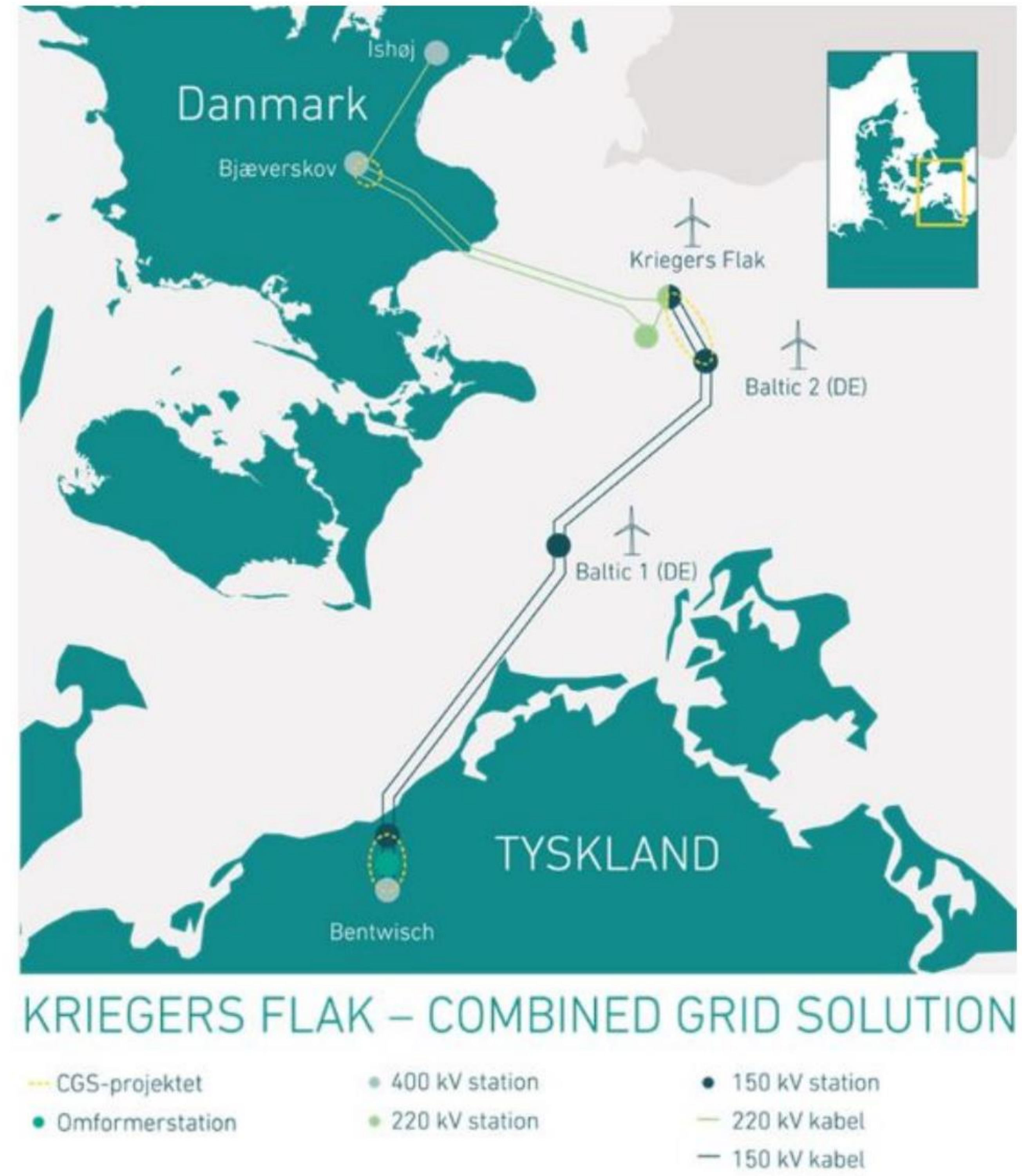


FIGURE 3. DANISH-GERMAN HYBRID INTERCONNECTOR [4]

congestion occurs in the high-voltage grid. Danish wind turbines were shut down even more due to stricter requirements to make capacity available on the West Danish-German border, while there are still expansion projects in the electricity grid on both the German and Danish sides, which during the construction period reduced the capacity of the wires—just as when motorway extensions create bottlenecks for traffic.

Figures 4 and 5 show Denmark’s wind power capacity and number of turbines since 1977, when the first turbine was connected to public grid. Today, the net installed wind power capacity is more than 6,000 MW. Of this total, offshore installed capacity accounts for 1,700 MW. Wind-generated electricity accounted for around 45% of total electricity consumption in the past five years.

Årlig tilvækst i anlæg og kapacitet/ Annual growth in number of turbines and capacity Danmark/Denmark

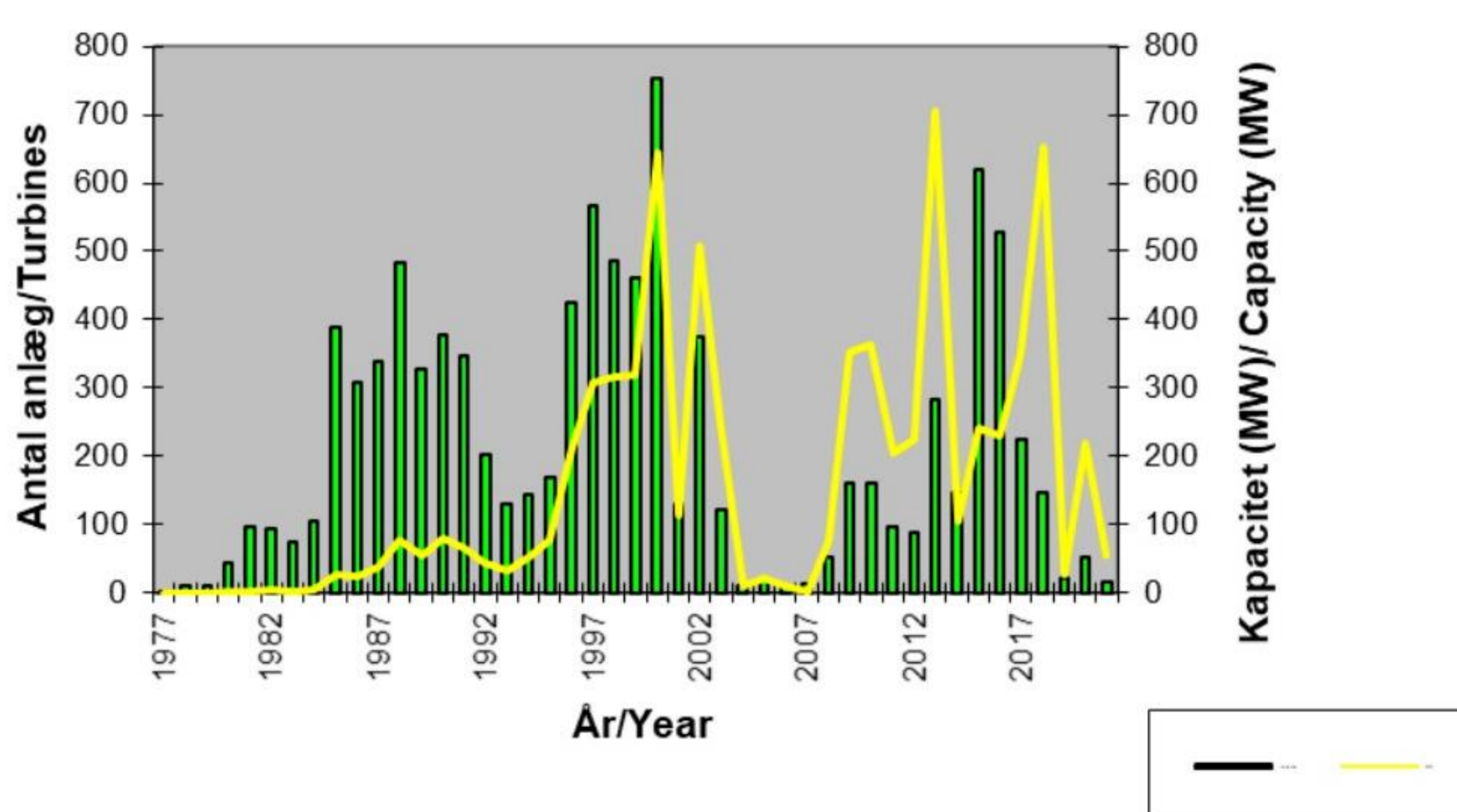


FIGURE 4. ANNUAL INSTALLED WIND POWER IN NUMBER OF TURBINES AND CAPACITY - DENMARK 1977 - 2020 [1]

Udvikling i anlæg og kapacitet/ Growth in number of turbines and capacity Danmark/Denmark

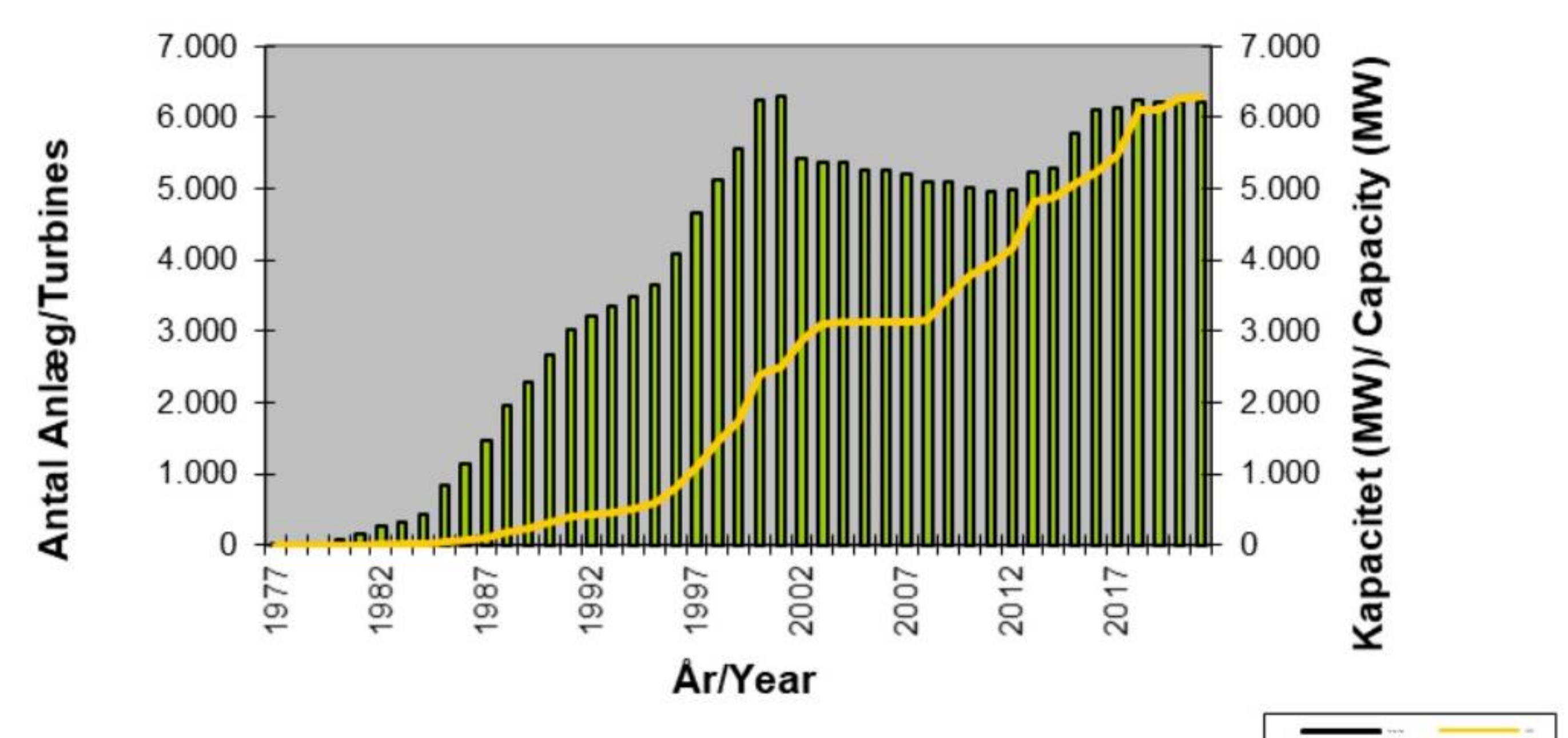


FIGURE 5. CUMULATIVE NUMBER OF TURBINES AND CAPACITY IN DENMARK 1977 - 2020 [1]



FIGURE 6. LARGE-SCALE SCREENING OF DANISH WATERS [7]

Matters affecting growth and work to remove barriers

Denmark is in a unique position to further expand the number of wind farms in Danish waters. The Danish Energy Agency has prepared a large-scale screening of Danish waters identifying locations suitable for the development of future offshore wind farms. The screening identified an area of about 35,000 km² suitable for the development of offshore wind. Under specific preconditions, the area can potentially serve as a basis for a minimum of 40 GW offshore wind. Of the identified 35,000 km², areas of total 11,000 km² have now been designated, with a potential of 12.4 GW [5]. These areas can be seen in figure 6.

R,D&D activities

National R,D&D priorities and budget

There was a small decline in public R&D budgets for wind energy in 2020. Ten new granted EUDP projects with a total granted amount of 113.188 mill. DKK (15.167 mill. EUR, 18.563 mill. USD). In 2019, 15 projects were granted. 83 running wind energy projects funded by IFD and EUDP and a few granted of the Independent Research Fund Denmark [6].

The two largest public funding programmes related to technical and societal energy solutions are The Energy Technology Development and Demonstration Programme (EUDP), administrated by The Danish Energy Agency, and Innovation Fund Denmark (IFD). Green Labs supports the establishment of large-scale test facilities for demonstration of new climate technologies.

EUDP presented a new investment strategy in 2020. The focus areas for wind are new materials, durability, recycling of turbine blades, better wind data, as well as challenges in upscaling.

Megavind research and innovation agenda 2020

As the national strategic platform for research, innovation, test, and demonstration in the Danish wind

2020 offered record high production from Danish wind turbines. In 2020, the Danish wind turbines delivered the equivalent of 47% of the Danes' electricity consumption and the share could have been around 51% if the production from wind turbines had not been down-regulated due to capacity problems in the electricity grid in Germany.

energy sector, Megavind is dedicated to identifying and promoting strategic innovation efforts that will push the wind industry further ahead. Megavind's annual report for 2020, containing recommendations for key stakeholders, addresses sustainability, physics, and economics with a special focus on reducing impacts throughout the wind turbine life cycle [7].

Strategic power to X alliance

The organizations Wind Denmark and Hydrogen Denmark have agreed to initiate a strategic collaboration with goals of securing the spread of Power-to-X (PtX) in Denmark and breaking down regulatory barriers. The two organizations have decided to name the collaboration 'The PtX-Alliance' [8]. The alliance is an important step towards enabling the possibility of renewable energy from wind turbines and solar PV to be used in production of hydrogen and other electrofuels through different methods, including electrolysis.

National research initiatives and results

Wind turbines can balance the electricity—a milestone

For the first time ever, wind turbines in 2020 have participated in the capacity market for manual reserves, and thus helped to provide the services that Energinet needs to ensure the balance in the electricity grid. A new pilot project shows that wind turbines—despite wind and weather—are reliable and can deliver exactly when needed. The project carried out by the energy trading group Energi Danmark and TSO Energinet shows that the forecasts are so good that they can deliver what they have promised in advance, and that the plants have the necessary regulatory properties. This is a major milestone for the green transition—it is simply a prerequisite that renewable energy sources can also provide balance services when the entire electricity system is to be green [9].

Examples of wind energy projects granted in 2020

- **GOTWind project**—Good bOITs for Wind turbines

TABLE 2: DANISH TEST AND RESEARCH FACILITIES 2020

Test Centre Høvsøre	Two additional test stands finalised in 2020 https://windenergy.dtu.dk/english/test-centers/hoevsoere_uk
Test Centre Østerild	Two new test stands have recently been added, and a new radar system is in place https://windenergy.dtu.dk/english/test-centers/oesterild
The Large-Scale Facility , DTU Risø Campus	https://windenergy.dtu.dk/english/Research/Research-Facilities/Large-Scale-Facility
Poul la Cour Wind Tunnel, DTU Risø Campus	https://windenergy.dtu.dk/english/Research/Research-Facilities/Poul-la-Cour-Wind-Tunnel
Lindø Offshore Renewables Center (LORC)	New grant in 2020 for a 66 kV grid emulator is to offer offshore wind turbine manufacturers and Power-2-X system manufactures the opportunity to test and validate system performance, efficiency and grid compliance under controlled grid circumstances. https://www.lorc.dk/test-facilities
Composite Laboratories, DTU Risø Campus	https://windenergy.dtu.dk/english/research/research-facilities/material_testing
The research wind turbine V52 DTU Risø Campus	https://windenergy.dtu.dk/english/Research/Research-Facilities/The-research-wind-turbine-V52
WindScanner	https://windenergy.dtu.dk/english/research/research-facilities/windscanner
Drivetrain Facility, DTU Risø Campus,	https://windenergy.dtu.dk/Forskning/Forskningsfaciliteter/Drivetrain

(2020-2023), EUDP grant 6.06 mill. DKK (0.8 mill. EUR / 1.0 mill. USD) and total budget 10.57 mill. DKK (1.4 mill. EUR / 1.7 mill. USD). Coordinator: DTU Wind Energy. The project objective is the optimization of bolt technology for wind turbines from production until end-of-life [10].

- **Offshore Hydrogen Wind Turbine project** (2021-2023), EUDP grant 9.5 mill. DKK (1.3 mill. EUR / 1.6 mill. USD) and total budget 17.53 mill. (2.3 mill. EUR / 2.9 mill. USD). Coordinator: Siemens Gamesa Renewable Energy A/S. The project investigates the concept of an offshore wind turbine with integrated electrolyzer as it eliminates the need for costly electrical infrastructure and the associated conversion losses [11].

Two EUDP projects finalised in 2020

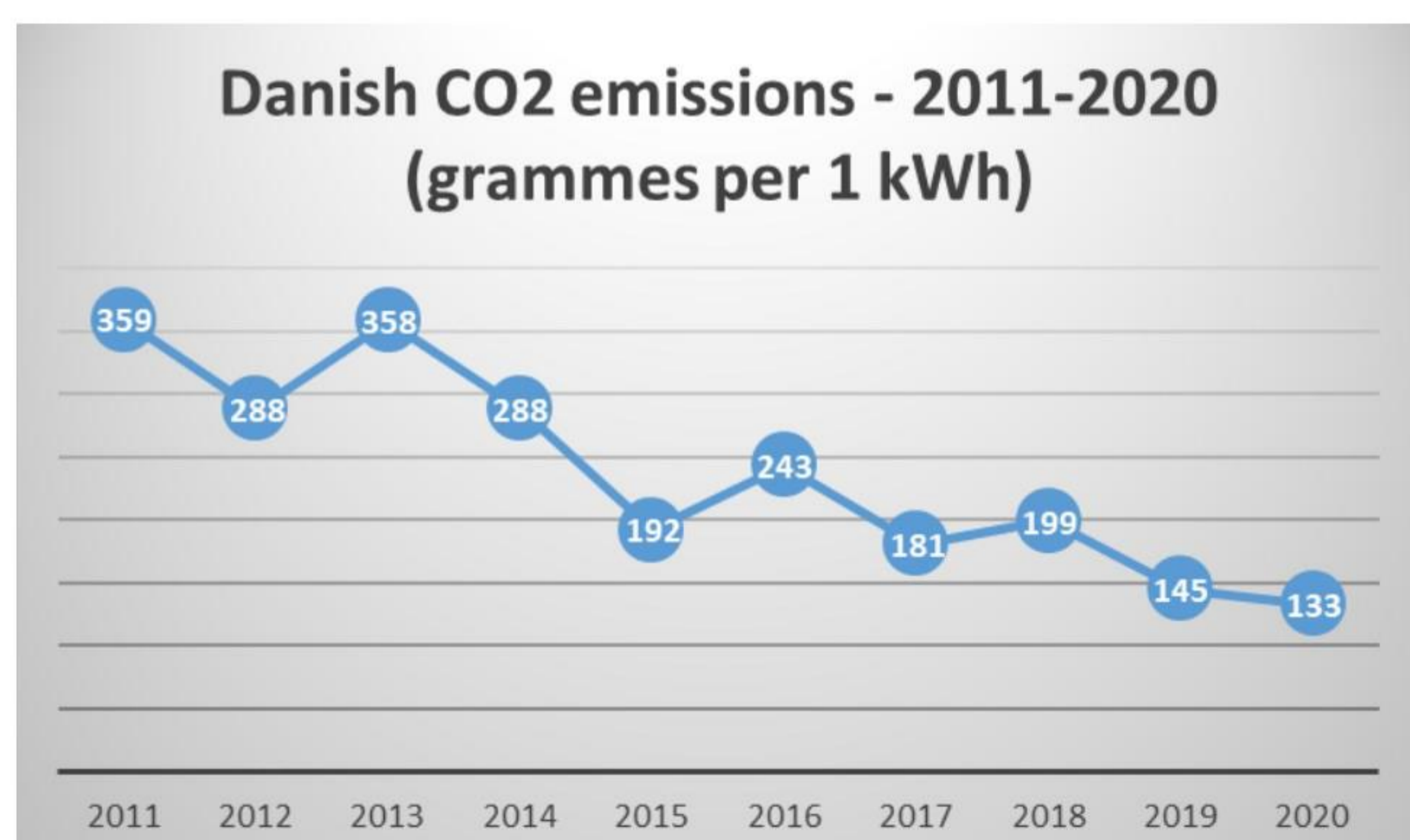
- **Offshore wind suction bucket on an industrial scale—part 2 Trial Installation** (2018-2020), Total budget 28.89 mill. DKK (3.8 mill. EUR / 4.6 mill. USD). Coordinator: Siemens Gamesa Renewable Energy A/S. The aim was to prepare the suction bucket for test installation and to demonstrate installation

in different types of seabed. Overall, the project has shown that the modular suction bucket can contribute to a cheaper production of foundations, cheaper transport, and a more efficient and simplified logistics around assembling the bucket structure on the quay. In the long run, this will mean a reduced price for green power from offshore wind turbines.

- **Power Pack WIND—hybrid installation generator for offshore wind turbines** (2017-2020). Total budget 5.62 mill. DKK (0.8 mill. EUR / 0.9 mill. USD). Coordinator: Zülau A/S. The purpose of the project was to build a hybrid generator unit that can supply offshore wind turbines with energy during periods when they are off grid. In collaboration with Ørsted A/S, the project has developed a system designed to function as a permanent installation in a wind turbine, and which can function as a supply unit and backup unit for the entire life of the turbine.

Test facilities and demonstration projects

The Danish Roadmap for Research Infrastructure 2020 presented 16 concrete proposals for new national research infrastructures. One of the proposals is

FIGURE 7: DANISH CO₂ EMISSIONS—2011-2020

NEST—The National Energy System Transition Facilities. The interconnection of the distributed energy system at DTU Risø Campus, a hybrid wind turbine at DTU Risø Campus, an electrofuel laboratory in Foulum, a power-to-x laboratory and a microgrid test laboratory at Aalborg University make it possible to use all the facilities' properties crosswise in a future energy system with integration [12].

Collaborative research

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

Impact of wind energy

Environmental impact

Danish electricity is still becoming more climate-friendly and green. Assuming that each kWh of wind-generated electricity displaces a kWh of average electricity consumption, the 16.35 TWh (16.17 TWh in 2019) of wind-generated electricity that Denmark produced in 2020 corresponds to the following environmental reductions (based on the environmental declaration from the Transmission System Operator (TSO) Energinet) [13]:

- 2.2 million tons of CO₂ eq (133 g/kWh)
- 0.654 tons of SO₂ (0.04 g/kWh)
- 4.09 tons of NO_x (0.25 g/kWh)
- 0.164 tons of particles (0.01 g/kWh)

If the wind power production is assumed to replace electricity production from coal, the environmental benefits are much larger. Wind energy covered 44% of an average Danish 1 kWh in 2020 including export/imports.

New guidelines on wind turbine acoustic noise

The Danish Environmental Protection Agency's revised wind turbine guidelines have been in public consultation in the autumn of 2020. Acoustic noise and visual effects remain important parameters in relation to limiting environmental impacts from wind power in Denmark [14].

Economic benefits and industry development

The year 2020 has offered a European order record of as much as 15 GW. 2020 was a record year for both onshore and offshore orders, both of which saw large increases in order intake, according to a report from WindEurope [15]. Many of the 15 GW orders were with companies located in Denmark with Vestas accounting for around 30% of the orders, Siemens-Gamesa with 27%, and MHI Vestas with 14% [16].

In 2019, the turnover in the wind turbine industry was DKK 112 billion (15 bill. EUR / 18.4 bill. USD)—an increase of almost 10% compared to 2018 and the second highest level to date, surpassed only by 2017.

In the entire wind turbine industry, the turnover was a total of 142.5 billion DKK (19.1 bill. EUR / 23.4 bill. USD). This is a decrease of just over DKK 7.5 billion from 2018. This has happened despite an increase in revenue in the wind turbine industry, and the decline can therefore be explained against the background of the development in the energy companies' turnover.

Revenue per man-years in the industrial part of the wind industry has increased to 3.6 million DKK in 2019 (0.48 million EUR / 0.59 million USD). The wind industry employed 33.159 full-time equivalents in 2019. The number of full-time employees increased by 1.1% from 2018 to 2019. In all, an estimated 2.3% of the private employees in Denmark work in the industrial part of the wind industry [17].

Newer data from 2020 will be available in the Danish Wind Industry Association's upcoming report entitled 'Branchestatistik 2021'.

A report published in 2020 by the Danish Maritime Fund and Danish Industry Association reached some interesting conclusions about employment effect of Danish offshore wind [18]:

- A Danish offshore wind farm of 1 GW equals 4,900 full-time jobs for Danish companies (14,600 when including indirect/induced effects)
- A European offshore wind farm of 1 GW contributes approximately 3,100 person-years to Danish offshore companies (9,100 when including indirect/induced effects).

- Danish offshore companies have increased their turnover in offshore wind from approximately 20% in 2010 to 40% in 2020. In addition, the revenue of Danish offshore companies corresponds to approximately 40% of the total investment in offshore wind in the EU in the last 10 years.

The wind export breaks records in 2019

For wind energy, a total of 66.5 billion DKK (8.9 billion EUR / 10.9 billion USD) was exported for in 2019. This is a record and is more than 50% of the total Danish energy export in 2019 [19]. However, from 2019 to 2020, the energy export decreased by 13%, with the wind energy export decreasing by 21% [20]. The drop in export can be explained partly by the pandemic, and partly due to lower sales to especially the European markets. The dramatic decrease should also be seen in connection to the record set in 2019. Compared to 2018, the 2020 numbers only dropped 3.4%.

Next term

In connection to the Energy Agreement from 2018, an offshore wind analysis will be prepared, contributing to the most optimal market framework so the offshore wind potential can be exploited commercially as soon as possible. The analysis will set up models for how revenue can be generated for the state as a result of the wind resource being utilized.

The new energy islands a pioneer project that will necessitate the deployment of existing knowledge into an entirely new context and will thus be carried out in collaboration with industry experts. The Danish Energy Agency plays a key role in realizing the project.

The Danish Energy Agency issued the Construction License for Danish Kriegers Flak on 3 February 2020 and in 2021, the 72 Siemens Gamesa wind turbines will be installed and put into operation in phases. Connection to the electricity grid is expected to be completed before the end of the year 2021.

Siemens-Gamesa has announced a 14MW prototype, which will have a rotor diameter of 222 metres and the ability to produce 25% more than its predecessor. The prototype will be ready in 2021 [21].

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