Denmark

Table 1. Key Statistics 2017, Denmark	
Total (net) installed wind power capacity	5.52 GW
Total offshore capacity	1.3 GW
New wind power capacity installed	0.37 GW
Decommissioned capacity (in 2017)	0.10 GW
Total electrical energy output from wind	14.8 TWh
Wind-generated electricity as percent of national electricity demand	43.4%
Average national capacity factor	32%
Target	50% renewable energy by 2030

OVERVIEW

Wind power capacity in Denmark increased by 275 MW in 2017, bringing the total to 5,521 MW (Table 1). The country installed 373 MW of new turbines—including 28 MW of new offshore wind (4 turbines)—and 98 MW were dismantled.

In 2017, 32% of Denmark's energy consumption came from renewable sources: 40% from oil, 15% from natural gas, 9% from coal, 2% from nonrenewable waste, and 2% from imported electricity. Wind-generated electricity met 43.4% of the domestic electricity supply (compared to 37.6% in 2016). The wind energy index was 102.3, compared to 90.2 in 2016. Recently, Denmark has focused on repowering land-based turbines, constructing four new large offshore wind farms, and developing new research test facilities.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

The Danish Government has an objective of 50% renewable energy by 2030. The existing agreement has been explained in earlier annual reports and can be found in the Danish Energy Agency's publication "Energy Policy in Denmark" (December 2012) [1].

In April 2017, the government-appointed Energy Commission presented its recommendations for a new energy policy to the Danish government. Denmark needs an ambitious, long-term energy policy as early as 2020, in order to reach the 2050 goal for a low-emissions society.

The commission considers the government's 2030 renewable energy target and the EU's CO_2 commitment as stepping stones along the road to 2050 [2]. The commission also provides important contributions to the preparation of the government's proposal for a new energy agreement. Parliamentary negotiations for the new agreement have been postponed from autumn of 2017 to 2018.

Progress & Operational Details

Figure 1 shows Denmark's wind-generated electricity production since 1977. The country added 275 MW of new wind power capacity in 2017, bringing the total to 5,521 MW, including small wind turbines. A total of 373 MW, comprised of 220 new turbines, were installed, while 98 MW (174 turbines) were dismantled (Figure 2).

Notably, 114 of the new turbines had a capacity at or below 25 kW. The largest rated turbine installed was an MHI Vestas 9.5-MW test turbine at the Østerild test site; unfortunately, this turbine had to be taken down after a fire in the hub. A detailed history of installed capacity and production in Denmark can be downloaded from the Danish Energy Agency website [3].

At the end of 2017, 6,157 turbines were operational, producing a total of 14.8 TWh—a new record for wind-generated electricity. The average capacity factor was 0.32 for those turbines, which have been in operation the whole year (average wind index 102.3). Beside the raising capacity, wind index fluctuations have influenced annual production. Over the last four years, the wind index has varied from 90.3 to 114.

Figure 1. Wind-generated electricity and share of electricity supply in Denmark

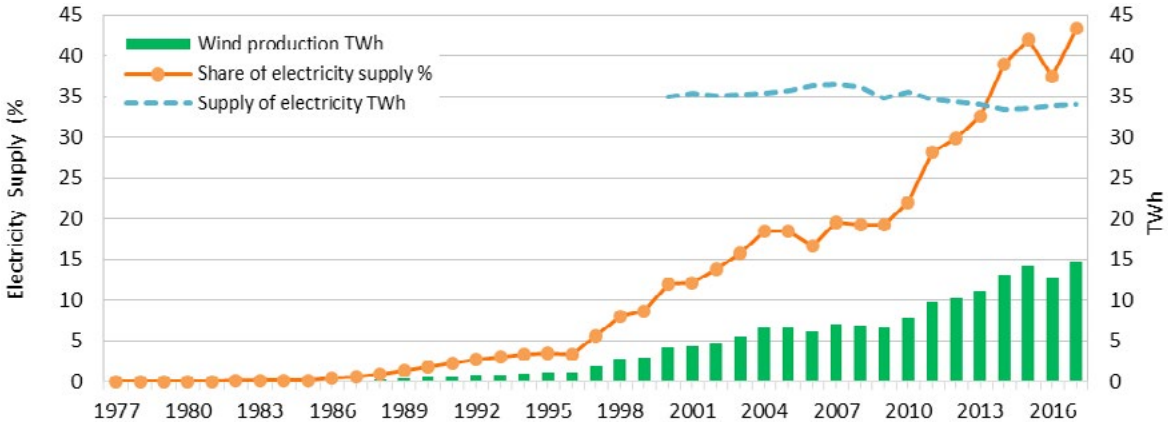
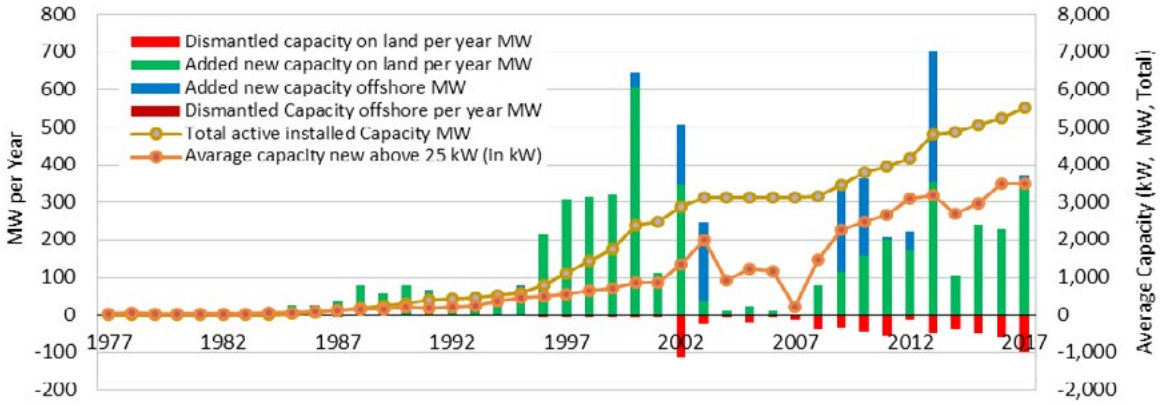


Figure 2. Added, dismantled, and total wind power capacity per year in Denmark



The 1,291 MW of offshore wind farms alone counted for 35% of Denmark's wind-generated electricity, (5.18 TWh) with an average capacity factor of 0.468. The average capacity of all installed turbines was 1,695 kW. The average capacity of the new turbines above 25 kW was 3,506 kW (Figure 2).

A 28-MW pilot offshore project in Nissum Broads, with four Siemens 7-MW turbines, was erected and put into operation at the end of 2017 [4].

Horns Rev III, with a capacity of 406.7 MW, will be constructed from 2017-2019 just North of Horns Rev II. The project will be using 49 MHI Vestas 164-8.3 MW turbines. The transformer platform, cables between the turbines, the sea cable to the shore, and transmission cable on land were completed during 2017, and all of 49 foundations were in place by the end of the year [5].

The 600-MW Kriegers Flak offshore wind farm will be constructed from 2018-2021. Here, developers have chosen to use 72 Siemens-Gamesa SWT-8.4 turbines. The wind farm is sited in the Baltic Sea between Denmark, Germany, and Sweden, near the future site of the German Baltic II offshore park. Energinet.dk and the German energy company Hertz 50 will be the first in the world to use offshore wind farm cables to connect power supplies between two countries [6].

Denmark has also continued planning for two nearshore wind farms: the 180-MV Vesterhav North and 170-MW Vesterhav South. Vattenfall has chosen the Siemens-Gamesa SWT-8.4 for both these projects [7].

Matters Affecting Growth & Work to Remove Barriers

In September 2017, the government signed an agreement that changes energy policy history in Denmark. For the first time, solar cells and wind turbines will compete to deliver the most green power to consumers.

There is a plan for two tender rounds in 2018 and 2019, with an approximate budget 800 million DKK (107 million EUR; 129 million USD). Support will be granted as a fixed price supplement on the electricity market price. Wind turbine projects already in the planning states will receive a transitional arrangement, and approximately 230 million DKK (31 million EUD; 37 million USD) will be allocated to support new test turbines.

It is expected that the tenders will result in approximately 140 MW of installed land-based wind and that approximately 125 MW of test turbines will also be installed. Up to 190 MW of land-based renewable energy can be accepted within the support system, depending on the bids, and approximately 130 MW of test turbines could be erected in the three-year support period.

Regarding offshore wind, Denmark, together with industry, has signed a declaration with Germany and Belgium that places greater emphasis on exploiting the potential of the North Sea for the construction of offshore wind farms.

Information on the status and progress of Danish offshore wind farms can be found on the Danish Energy Agency English website, including a new English publication on the Danish regulatory framework for offshore wind and the achieved results [8].

National R,D&D Priorities & Budget

The Danish Energy Agency administers the Energy Technology Development and Demonstration Program (EUDP) [9]. This R&D program was established by law in 2007 to support the development and demonstration of new technologies in the energy field. EUDP supports new technologies that can contribute to Denmark's energy and climate goals.

Since the creation of the program, more than 600 projects have been initiated with funding, for a total of 3 billion DKK (402 million EUR; 483 million USD). The partners behind the projects have matched EUDP funding with an equivalent amount. The former program, ForskEL (Energinet.dk), merged with EUDP in 2017. EUDP has published a new strategy for 2017-2019, which focuses on energy technologies for international markets in the coming years [12].

Priorities and funding are based on an analysis of the following three topics:

- Global trends and challenges in the energy sector
- Business potential and strongholds of Danish businesses in the energy sector
- Danish energy-sector strongholds in research, development and demonstration

The Danish Energy Agency's ELFORSK program supports projects that ensures more efficient electricity use for consumers [10]. The Ministry of Education and Research's program, Innovation Fund Denmark, focuses on supporting more fundamental innovation [11].

An overview of these programs was published in a 2017 report entitled "Energy17" [13]. Figure 3 shows the development of total grant funding and the share to wind energy. Detailed information on funded projects, as well as developments of the granted funds over the last 10 years, can be found on the "Energiforskning" website [14, 15].

National Research Initiatives and Results

Megavind is Denmark's national partnership for wind energy, and the Danish equivalent of the European Technology and Innovation Platform on Wind Energy (ETIPWind). The partnership acts as catalyst and initiator of a strengthened strategic agenda for research, development and demonstration. Their latest report, *Annual Research and Innovation Agenda* (Nov 2017), provides specific priorities and recommendations for Danish funding programs [16].

DTU Wind Energy collaborated with LM Wind Power to develop a new method for observing how fatigue damages evolve in reinforced composite materials inside wind turbine blades [17]. The new technique makes it possible to identify how and where the damages begin and how they develop when composites are exposed throughout a turbine blade's lifetime.

New wind scanner developments have contributed to one of the most interesting research results in Denmark in recent years. Thanks to developments at DTU Wind Energy, Lidars have been used to measure wind 3-5 km in front of a wind farm, which hits the turbines 5-10 minutes later [18].

During 2017, the DTU Risø Campus tested a 4-Rotor Concept Turbine (so named because it has four rotors instead of the usual one) designed by Vestas. The 4-rotor Concept Turbine is part of research into whether wind energy can become more cost-competitive by delivering more wind-generated electricity while reducing the weight. Tests are carried out by Vestas, with researchers from DTU Wind Energy offering counselling and meteorological services [19].

Test Facilities & Demonstration Projects

Denmark has many test facilities, such as the Lindø Offshore Renewables Center (LORC), the Test Center for Large Wind Turbines at Høvsøre, the Østerild National Test Centre for Large Wind Turbines, and the test field and Powerlab at DTU Risø Campus. Detailed information on the activities and test sites at DTU and LORC can be found at their websites [20, 21].

In March 2017, it was decided to expand the two wind turbine test centers at Høvsøre and Østerild with a total of four new test sites. These new sites will make it possible to test more advanced technology and higher turbines (up to 330 meters in Østerild and up 200 meters in Høvsøre).

Construction of the new Large-Scale Facility at DTU—part of the Villum Center for Advanced Structural and Material Testing (CASMaT)—was completed during 2017, and operations began at this facility in November [22].
A new wind tunnel, The Poul la Cour Wind Tunnel, is currently under construction at the DTU Risø Campus. The tunnel is financed by the Danish Agency for Science and Higher Education and Region Zealand and is expected to be operational in April 2018 [23].

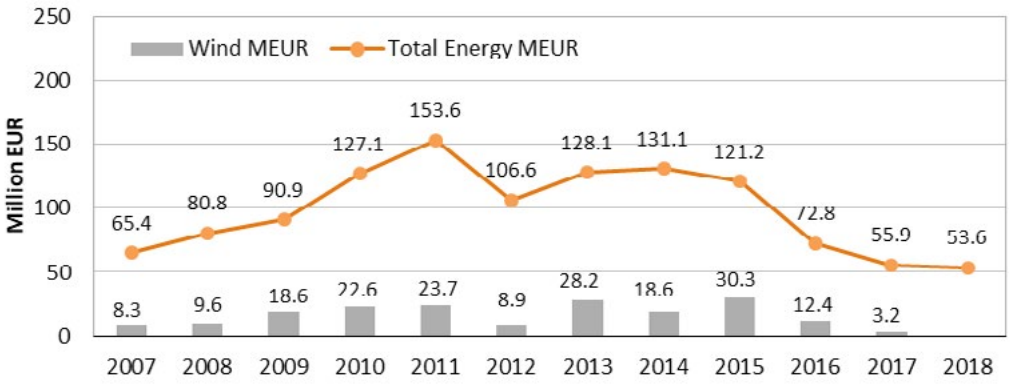


Figure 3. Energy R&D funding in Denmark (2018 is the budget for EUDP only with no specific amount allocated for wind)

Collaborative Research

Denmark utilizes public support to enable Danish companies, universities, and research institutions to take part in international co-operation. Denmark's work helps to promote R,D&D for energy technologies in TCPs under IEA, EU programs, and Nordic Energy Research programs.

IMPACT OF WIND ENERGY

Environmental Impact

Assuming that 1 kWh of wind-generated electricity substitutes 332 g of coal, the 14.8 TWh Denmark produced in 2017 would have resulted in the following reductions [24]:

- 11.4 million tons of CO_2 (772 g/kWh)
- 772 thousand tons of cinder and ash (52.3 g/kWh)
- 1,034 tons of SO_2 (0.07 g/kWh)
- 2,658 tons of NO_X (0.18 g/kWh)
- 295 tons of particles (0.02 g/kWh)

Economic Benefits & Industry Development

In 2016 the Danish wind industry achieved the highest turnover in seven years—close to the record levels in 2008 and 2009. Turnover rose 10.6%, from 14.2 billion EUR (17.0 billion USD) in 2015 to 15.7 billion EUR (18.8 billion USD) in 2016.

Exports rose 16% in 2016, reaching 7.4 billion DDK (1 billion EUR; 1.3 billion USD) and accounting for 4.1% of the total Danish exports. At the same time, employment grew 6.2%, from 31,251 employees in 2015 to 32,898 in 2016.

Newer data from 2017 can be found in Danish Wind Industry Association's report entitled *Branchestatistik 2017* (released June 2018) [25].

NEXT TERM

During the next three to four years, Vattenfall alone will add 1,350 MW of offshore wind capacity, with Horns Reef 3, Kriegers Falk, and the nearshore North Sea South and North Sea North. Denmark is also expecting an additional 150 MW of land-based wind. In a few years, wind turbines will supply the approximately 60% of Denmark's electricity consumption.

The Danish government is expected to present a proposal for a new Energy Agreement in 2018, which will replace the Energy Agreement from March 2012. Negotiations should have started in 2017, but were postponed to 2018.

References

Opening photo: The La Cour Wind Tunnel (Courtesy of DTU Wind Energy)

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