



Table 1. Key Statistics 2018, Denmark

Total (net) installed wind power capacity	6.124 GW
Total offshore capacity	1.7 GW
New wind power capacity installed	0.657 GW
Decommissioned capacity (in 2017)	0.022 GW
Total electrical energy output from wind	13.893 TWh
Wind-generated electricity as percent of national electricity demand	41.7%
Average national capacity factor	24.4%
National wind energy R&D budget	175 mil DKK; 23.4 mill EUR; 26.8 mil USD
Target	55% renewable energy by 2030

OVERVIEW

Installed wind power capacity increased by 657 MW in 2018, including 437 MW of new offshore wind power. This brings Denmark's total capacity to 6,124 MW (Table 1). In 2018, 33% of Denmark's energy consumption came from renewable sources; 38% from oil, 15% from natural gas, 9% from coal, 2% from non-renewable waste, and 3% from imported electricity [2]. Wind-generated electricity met 41.7% of the domestic electricity supply (the highest in Europe) compared to 43.4% in 2017. The wind energy index in 2018 was 90% compared to 102% in 2017.

In June, the Dutch government presented the National Energy Agreement, which includes binding commitments. Under this agreement, the planning expands the supply of energy from offshore wind by at least 2,400 MW. Thus, Denmark will have approximately 2,650 MW of offshore wind power installed by 2023, followed by an additional minimum of 2,400 MW by 2030. Other important areas covered by the Energy Agreement are a new support scheme for experimental wind turbines, and technology-neutral tenders.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

On 29 June 2018, the Danish Parliament made an Energy Agreement based on political agreement between all political parties which will be valid for the period 2020 to 2024 [3]. For wind energy, three offshore wind farms will be established to meet the 2,400 MW target by 2030.

The agreement includes a screening process to identify offshore wind farm locations for 10 GW of installed capacity in the Danish waters of the North and Baltic seas. This is in line with the aim that renewable energy must be able to cope with market conditions.

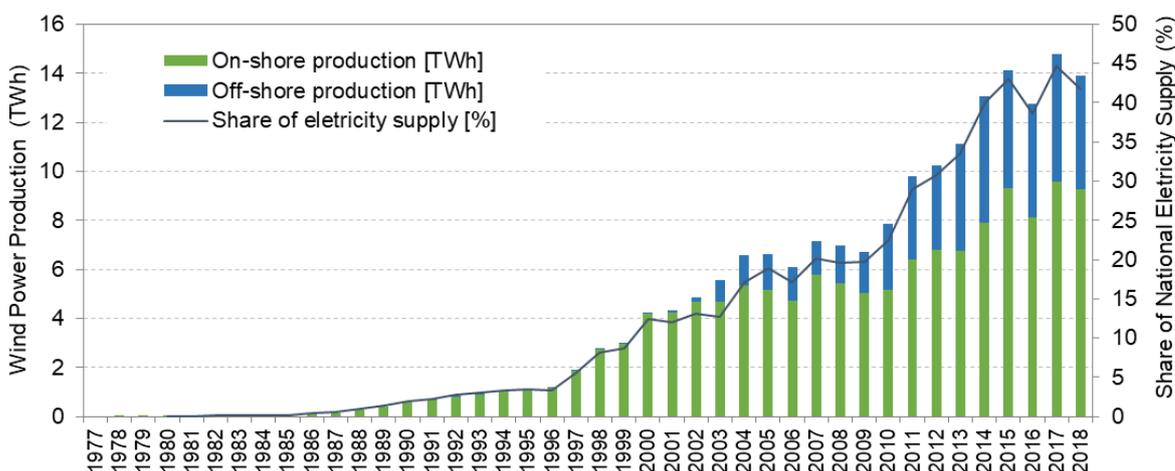


Figure 1. Wind-generated power and share of the national electric energy supply in Denmark since 1977 [1]

Technology-neutral tenders of solar photovoltaics, land-based and nearshore wind power, wave power, and hydroelectric power will be supported by an allocation of 561 million EUR (643 million USD) during the agreement period.

The number of land-based wind turbines larger than 25 kW will be reduced from the current level of approximately 4,300 wind turbines to a maximum of 1,850 in 2030. The policy will be gradually implemented during the agreement period, based on annual reviews and ongoing monitoring of progress.

After 2020, the parties intend to increase public funding for research, development, and demonstration projects in the fields of energy technology and climate. During the agreement period, funding for these efforts will increase to 134 million EUR (153 million USD).

These funds will be prioritized within the framework of the government's goal of investing at least 1% of GDP in research. The Energy Agreement expects to invest approximately 66 million EUR (76 million USD) in 2019, increasing to approximately 374 million EUR (428 million USD) in 2025.

Based on the Energy Agreement, direct support for new household wind turbines ceases in 2020 [4]. However, a scheme supporting installation of test or prototype wind turbines is established for installations either inside or outside the national test centers.

Progress & Operational Details

Figure 1 shows Denmark's wind-generated electricity production 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 close to 45% of total electricity consumption in the past five years.

Figure 2 shows how the monthly wind-generated electricity production varies during 2018 and 2017, as well as a five-year average.

The accumulated wind power capacity related to a design lifetime of 20 years. As of the end of 2018, 6,125 MW of wind power capacity has been installed. In 2000, this number was approximately 2,000 MW. Thus, by 2020 more than 30% of the installed capacity will be over 20 years old (Figure 3).

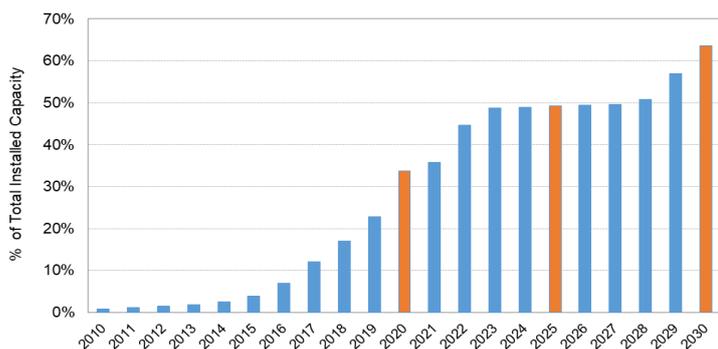


Figure 3. Installed capacity exceeding design lifetime of 20 years (%)

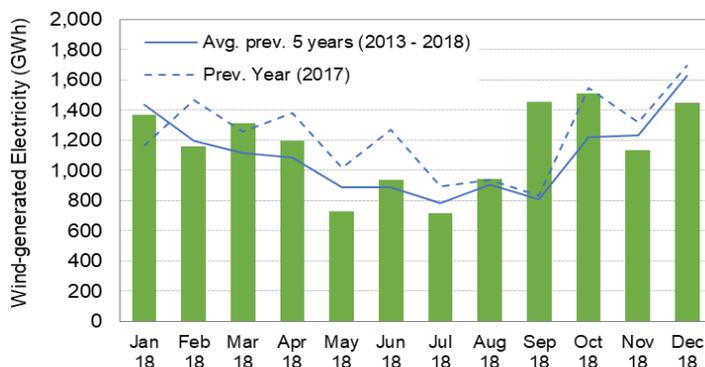


Figure 2. Monthly wind-generated electricity production [1]

Figure 4 illustrates the wind power capacity in MW that is provided by installations which exceed the 20-year lifetime on an annual basis. Both Figure 3 and 4 only take into account the installed capacity. Projects in the pipeline or in the planning stage are not included.

Matters Affecting Growth & Work to Remove Barriers

With the Energy Agreement of 29 June 2018, the first Danish technology-neutral tender was launched in 2018 for wind energy and photovoltaic projects for access to funding of 32 million EUR (37 million USD). The next tender is planned for 2019.

The result of the tendering in 2018 was three contracts for 138 MW of land-based wind projects and three contracts for 104 MW solar PV projects with an average premium of 0.31 EUR/kWh (0.35 USD/kWh).

Announcements from large IT companies such as Apple, Google, and Facebook, which plan build data centers in Denmark, led to a debate on how such data centers might stand in the way of Denmark's transition to green power. Apple has announced that the company wants to be green-energy self-sufficient and plans to build a wind farm and solar power plant for that purpose.

Several RE investors have recently announced that they will install wind and/or solar PV projects without state aid. It is expected that this trend will continue, and could even advance further with the increase in power-purchase-agreements (PPA's) between RE investors and large power consumers such as data centers.

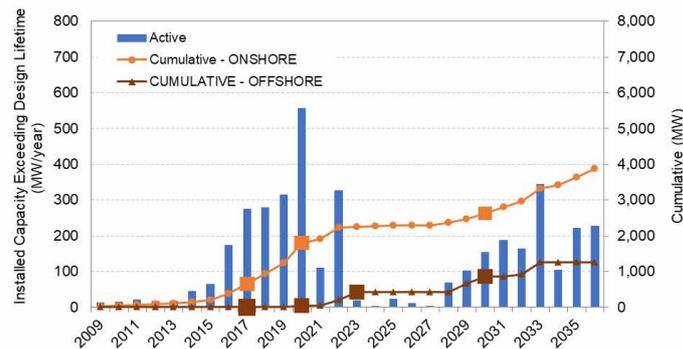


Figure 4. Annual installed capacity exceeding design lifetime of 20 years (MW/year)

R,D&D ACTIVITIES

National R,D&D Priorities & Budget

The two largest public funding programs related to technical and societal energy solutions are The Energy Technology Development and Demonstration Programme (EUDP) and Innovation Fund Denmark (IFD) [5, 6]. Financial support is given in accordance with EU state aid rules, including that foreign project participants can receive EUDP support according to the same rules as Danish participants.

The Danish Energy Agency administers EUDP, which supports private companies and universities to develop and demonstrate new energy technologies, including wind energy. Innovation Fund Denmark supports strategic and applied energy research. Innovation Fund Denmark has a specific energy investment strategy, which was updated in 2018.

In 2018, EUDP and IFD granted 18 wind power R&D projects a total of 175 million DKK (23.4 million EUR; 26.9 million USD). Detailed information on funded projects and public energy research can be found on each project website [5-8].

Megavind is Denmark's national partnership for wind energy, representing both industry and research organizations. The 2018 Megavind annual research and innovation agenda outlined six key R&D themes that were derived directly from Danish companies' internal R&D roadmaps. The R&D themes were further supported by five so-called innovation drivers that provide criteria for assessing the potential impact of R&D projects [9].

R&D priorities in Megavind also reflect the R&D priority developments at the European level, undertaken in the European Technology and Innovation Platform for Wind Energy (ETIPWIND) and the Joint Programme for Wind Energy under the European Energy Research Alliance (EERA JP WIND).

In September, the Ministry of Higher Education and Research approved the Energy Innovation Cluster (EIC) as Denmark's innovation network for land-based and offshore energy production with a grant of 1.6 million EUR (1.8 million USD) and a total project portfolio of over 52 million EUR (60 million USD). EIC will focus on the value of the innovation-promoting effort, with wind industry and universities as members [10].

National Research Initiatives and Results

The results of publicly funded wind energy projects in 2018 are available at the national energy research portal [7]. Examples of projects are listed below:

The LifeWind project completed inspection of several wind turbines for life extension in October 2018 [17]. This EUDP-funded project aims to demonstrate procedures that can quantify the risk of failure, the remaining structural reliability, and the maintenance costs when operational wind turbines exceed their certified life. These procedures are based on the level of available data that is recorded.

In December 2018, Vestas dismantled its 900-kW multi-rotor concept after a two-and-a-half-year testing and validation campaign [18]. The Danish manufacturer observed many

technical benefits from the four-turbine prototype, including a 1.5% power gain. The turbine was installed at the test site of DTU Wind Energy, Risø Campus, in early 2016 as a research and development project.

The results of a Danish health study (conducted from 2015 to 2019) with research on possible connections between wind turbine noise and health effects was published during 2018 and completed in February 2019 [11]. The study compares data on cardiovascular disease, diabetes, negative birth outcomes and redemption of prescriptions for blood pressure medicine, sleeping medication, and antidepressants with exposure to the calculated average nocturnal outdoor and indoor noise from wind turbines. The study has not provided conclusive evidence of a correlation between exposure to wind turbine noise and the triggering of blood clots in the heart or stroke.

In 2018, EUDP funded the project RELIABLADE - Improving Blade Reliability through Application of Digital Twins over Entire Life Cycle. RELIABLADE (2018 to 2022) develops and demonstrates techniques to create a unique Digital Twin for each individual wind turbine blade with their unique defects and imperfections.

Test Facilities & Demonstration Projects

In order to support development of large wind turbines, the Danish government set up a special pool of 26 million EUR (30 million USD) as FIT (feed-in-tariffs) for experimental and test wind turbines in 2018 and 2019. The funds are awarded on a first-come, first-served basis. At the national test centers in Høvsøre and Østerild, the 2018 support FIT of 0.017 EUR/kWh (0.02 USD/kWh) was granted for a three-year period. If established outside the two national test centers, the turbines are exempted from tendering process and can receive a FIT for 20 years at 0.014 EUR/kWh (0.016 USD/kWh) in 2018, and the average of the land-based tendering bids in 2018 when presented in 2019.

In 2018, the Parliament decided that the two national test centers, operated by DTU Wind Energy in Østerild and Høvsøre, can be expanded with two test sites each. This would allow for the testing of nine wind turbines in Østerild and seven wind turbines in Høvsøre.

The construction of the new Large-Scale Facility at the DTU Risø Campus—part of the Villum Center for Advanced Structural and Material Testing (CASMAT)—was completed in 2017, and operations began in November [16]. The Poul la Cour Wind Tunnel was inaugurated in April 2018. The wind tunnel's combination of Reynolds Number and acoustic properties is unique in the world [12]. It received support from the Danish Agency for Science and Higher Education and Region Zealand.

Collaborative Research

Denmark utilizes public support to enable Danish companies, universities, and research institutions to participate in collaborative international projects. Denmark's work helps to promote R,D&D for energy technologies in TCPs under the International Energy Agency (IEA), the European Union, and Nordic Energy Research programs.

Environmental Impact

Assuming that each kWh of wind-generated electricity displaces a kWh of average electricity consumption, the 13.9 TWh of wind-generated electricity that Denmark produced in 2018 corresponds to the following environmental reductions (based on the environmental declaration from the Transmission System Operator (TSO) Energinet.dk) [13]:

- 2.8 million tonnes of CO₂ (199 g/kWh)
- 556 tonnes of SO₂ (0.04 g/kWh)
- 2.49 tonnes of NO_x (0.17 g/kWh)
- 139 tonnes of particles (0.01 g/kWh)

On the basis of a number of EU judgments, the Ministry of the Environment and Food in 2018 has carried out an environmental assessment of the executive order on acoustic noise from wind turbines [14]. Simultaneously, the Ministry revised the Executive Order with a number of technical changes based on new professional knowledge. The Executive Order was revised in the following areas: regulation of clearly audible tones; differentiation between sound insulation figures for cottage areas and for ordinary housing; adjustment of the calculation method for sound propagation above water; adaptation of the transitional provisions; and equality of supervision for offshore and land-based wind turbines.

The aim of promoting social acceptance of onshore windfarms means that revision will be made to the existing RE-schemes. In relation to the value-added scheme, a sales option scheme will be introduced. The buyer scheme will be reviewed in order to ensure that it is prepared for future developments with larger turbines. Finally, a fund construction is in preparation, replacing the former green scheme. The intention is to promote municipal incentives for increased renewable energy by giving wind turbine developers the opportunity to give direct subsidies to the municipality to promote local or recreational values in the municipality as well as cultural and informative activities.

Economic Benefits & Industry Development

In 2017, the Danish wind industry once again achieved a new record in turnover. Turnover rose 20.4%, or 3.2 billion EUR (3.7 billion USD), from 15.9 billion EUR (18.2 billion USD) in 2016 to 19.2 billion EUR (22 billion USD) in 2017.

Exports in 2017 reached 1.1 billion EUR (1.3 billion USD) and accounted for 3.7% of total Danish exports. From 2016 to 2017, the industry experienced a decline in exports of 3%, which is due to fluctuations in the number of large offshore wind turbine projects and to the wind turbine market decreasing a larger share of the Danish production of wind turbines than usual. At the same time, employment grew 6.2%, from 31,201 in 2016 to 31,871 in 2017. Since 2006, employment in the wind industry has increased 15.8%. At the same time, exports have increased by 37.6%, while turnover increased by 55.8%.

Newer data from 2018 will be available in the Danish Wind Industry Association's report entitled "Branchestatistik 2019" (expected release June 2019) [15].

- The coming years will reveal the effects of the 2018 energy agreement. The biggest impact is expected to be installation of a minimum 2,400 MW of offshore wind power capacity in the next decade.
- The first wind farm (Thor) organized under the Energy Agreement will be out for tender in 2020. The call will be a combined call covering both the offshore wind farm and the grid connection infrastructure in terms of offshore substation, export cables, and onshore substation. to the national TSO.
- The future research agenda is expected to focus on system integration and digitalization of wind energy.
- New orders on acoustic (noise) and certification will be developed and implemented.
- Denmark will work for development of The North Sea Energy Cooperation.
- Danish parliament is expected to pass a new climate law with binding goals and measures towards a fossil free society by 2050, including new goals for RES and wind power.

References

Opening photo: The National Test Center Østerild (Courtesy of DTU Wind Energy).

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