19 Denmark

1.0 Overview

In 2014, 25.5% of Denmark's energy consumption came from renewable sources: 40% from oil, 16% from natural gas, 15.1% from coal, and 2.3% from nonrenewable waste. The production from wind turbines alone corresponded to 39.1% of the domestic electricity supply, compared to 32.7% in 2013.

Wind power capacity in Denmark has increased by 77 MW in 2014, bringing the total to 4,896 MW (Table 1). In 2014, 106 MW of new turbines were installed while 29 MW were dismantled. No new wind turbines were installed offshore in 2014. The largest rated turbine to be installed in 2014 was the 8-MW Vestas erected at Oesterild test site in the beginning of 2014.

2.0 National Objectives and Progress

The Energy Agreement from March 2012 is still the latest political Energy Agreement in Denmark.

The content of the agreement has been explained in earlier annual reports and can be found in the in the report "Accelerating green energy towards 2020" [1], the publication "Energy Policy in Denmark," Danish Energy Agency, December 2012 [2] and in the Minister's report to parliament in April 2013 [3].

A number of reports and recommendations to follow up the agreement were released during 2014. In January, the Danish Energy Agency prepared documents (in Danish) on coordination of the planning process on land [4] and on the terms, procedure, and responsibilities for the grid connection of near-shore wind farms [5]. Energinet.dk released a technical project description on near-shore wind farms [6]. The tendering processes for both large and near-shore wind farms was prepared in 2014 and will take place in 2015 (reports and information can be downloaded from www.ens.dk [7] and www.energinet.dk [8].

In July 2014, the Danish government and the Parliament revised the agreement about financing the future development of wind Power. The revision includes a reduction in the cost to public service obligation (PSO) for both industry and private households, which partly finance the wind development up to 2020. The result is an extension of the period for construction of Kriegers Flak to 2022 and a reduction of the plans for near-shore offshore wind farms with 100 MW from a total of 500 MW to 400 MW. However, the future wind share still will be above the 50% by 2020 goal, and increase further when Krieger Flak is in full operation in 2022. Also, an increase in capacity of new land-based wind is expected up to 2020.

2.1 National targets

The Wind Power the Agreement now includes:

- 1,000 MW of large-scale offshore wind farms before 2022 (tendering process)
  - o Horns Rev III 400 MW (in operation in 2017–2020)
  - o Krieger Flak 600 MW in operation before 2022 (EU support to grid connection 1.1 billion DDK (1.5 million EUR; 1.8 million USD)),
- 400 MW near-coast offshore installations (tendering process) including 50 MW of offshore turbines for R&D (according to the reduction mentioned above).
- 500–600 MW of added capacity on land before 2020; 1,800 MW new land-based including 1,300 MW for repowering.

2.2 Progress

As shown in Table 1 and Figure 1, the contribution from wind alone to the domestic electricity supply was 39.1% in 2014 compared to 32.7% in 2013.

The added net wind capacity in Denmark in 2014 was 77 MW, bringing the total to 4,896 MW (Table 1). In 2014, 105 MW (93 new turbines) were installed all on land, while 29 MW (69 turbines) were dismantled

Production from wind turbines in 2014 corresponded to 39.1% of the domestic electricity supply, compared to 32.7% in 2013.

Table 1. Key National Statistics 2014: Denmark	
Total (net) installed wind capacity	4,896 MW
New wind capacity installed	77 MW
Total electrical output from wind	13.1 TWh
Wind generation as percent of national electricity demand*	39.1%
Average capacity factor**	30.8%
Target***	50% wind energy by 2020

*In 2014, the wind index was 99.7%
**Average Capacity factor based on production from turbines installed before 1 January 2014
***Out of electricity demand

(Figure 2). A large part of the dismantled capacity came from come from one wind farm in Northern Jutland (Klim), where 35 600-kW turbines were dismantled to make room for a new windfarm in 2015 with 22 new 3.2-MW turbines owned by Vattenfall.

Figure 3 shows capacity and production of wind turbines in Denmark since 1980, A detailed history of installed capacity and production in Denmark can be downloaded from the Danish Energy Agency Web site [7]. The largest rated turbine installed in 2014 was the 8-MW Vestas erected at Oesterild in January 2014 (Figure 4).

The environmental benefits due to the 2014 wind energy production have been calculated using preliminary data. Assuming coal is being substituted, saved coal = 4,246,856 tons (325 g/kWh); reduced CO_2 = 9,745,872 tons (746 g/kWh); reduced SO_2 = 1,045 tons (0.08 g/kWh); reduced NO_X = 2,874 tons (0.22 g/kWh); reduced particles = 392 (0.03 g/kWh); and reduced cinder/ash 701,546 tons (51 g/kWh) [9].

2.3 National incentive programs

Information about the existing incentive programs can be found in the *IEA Wind 2013 Annual Report*.

In 2014 new feed-in premium tariffs were introduced for small wind turbines connected to the grid after November 2012, but due to EU regulation of subsidies they have not come into force before February 2015. For turbines with a capacity of 10 KW and below, the market price plus the feed-in premium is 2.5 DDK/kWh (0.34 EUR/kWh; 0.41 USD/kWh) for power delivered to the grid. For turbines with a capacity between 10 kW and 25 kW, the price is 1.5 DDK/kWh (0.20 EUR/kWh; 0.25 USD/kWh). The tariffs for small wind turbines are valid for a total capacity up to 2.5 MW and will be evaluated depending on the development

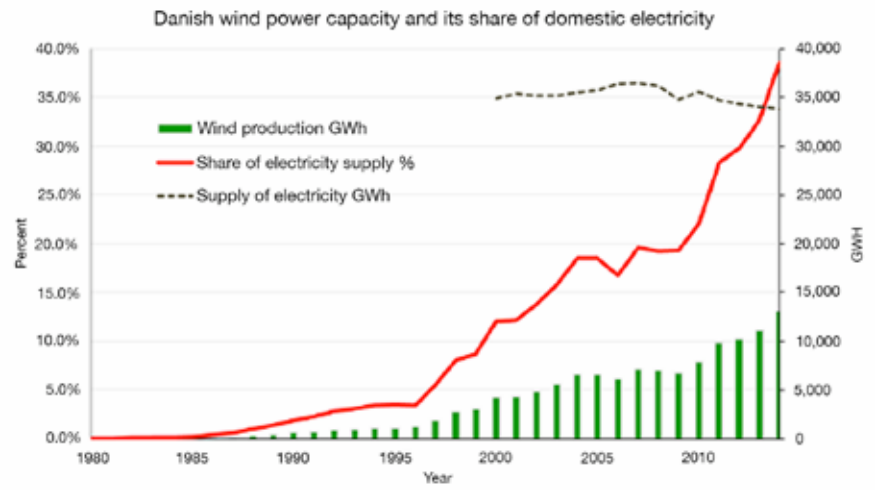

Figure 1. Danish wind power capacity and share of domestic electricity supply from 1980–2014

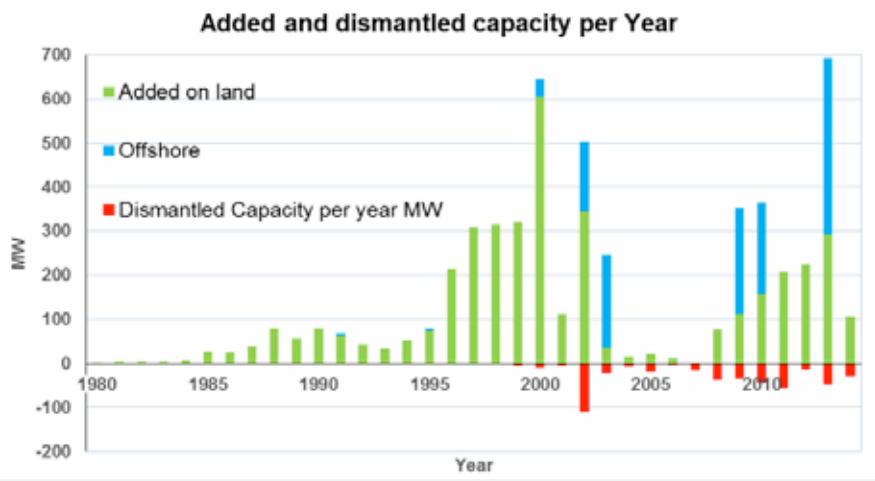

Figure 2. Added and dismantled capacity per year

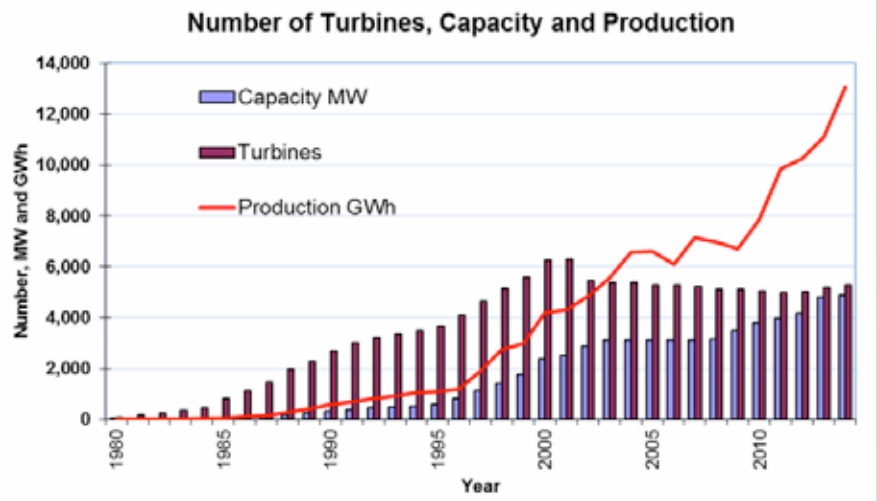

Figure 3. Development in number of turbines, capacity and production

and future EU regulation for feed-in premium systems after 2016.

2.4 Issues affecting growth

In 2014, 93 MW of new turbines were installed in Denmark. Of those, 56 turbines had a capacity below 25 kW, and 36 had a capacity between 2 MW and 4 MW. One 850-kW turbine was moved to another site. During the year, 69 smaller and older wind turbines were dismantled, representing a capacity reduction of approximately 29 MW (Figure 2).

3.0 Implementation

3.1 Industry

The wind turbine industry's annual report *"Branchestatistik 2015"* [10] includes statistics for 2014.

The turnover in 2014 was 84.4 billion DKK (11.3 billion EUR; 13.8 billion USD) compared to 78.6 billion (10.5 billion EUR; 12.8 billion USD) in 2013. The industry exported 53.5 billion DKK (7.2 billion EUR; 8.7 billion USD) in 2014 compared to 45.8 billion DKK (6.1 billion EUR; 7.5 billion USD) in 2013, which is an increase of 16.7%.

3.2 Operational details

The largest projects are the five offshore farms: Horns Rev I and II in the North Sea, Nysted and Roedsand II in the Baltic Sea, and Anholt (400 MW). Maps of existing offshore winds farm can be found in earlier annual reports or in [7].

At the end of 2014, 5,269 turbines with a capacity of 4,896 MW were in operation and the total production in the year was 13.1 GWh. The average capacity factor was 30.8% (average wind index 99.7%) for the turbines, which have been in operation the whole year. The 1,271 MW of offshore wind farms alone counted for 40% of the production with an average capacity factor of 46.4%.

The largest rated turbine to be installed in 2014 was the 8-MW Vestas erected at Oesterild in January 2014. The total amount of wind power in the grid system rose to nearly 39.1% in 2014 compared to 32.7% in 2013.

The average capacity of turbines installed fell to 1.1 MW in 2014 because of installation of many small household turbines. The average capacity of the 36 turbines above 1 MW was nearly 2.9 MW.

Figure 4. Vestas 8-MW wind turbine (Courtesy of Vestas Wind Systems A/S)

4.0 R, D&D Activities

An annual report on the energy research program's budget, strategy, and projects by technology is published in cooperation among Energinet.dk, the Energy Technology Development and Demonstration Programme (EDDP), the Danish Council for Strategic Research (DCSR), the EC representation in Denmark, and the Danish Advanced Technology Foundation. The 2014 report is expected to be available in May 2015 together with an updated list of Danish funded energy technology research projects available online at (www.energiforskning.dk).

4.1 National R, D&D efforts

Since 2007, the main priorities for R, D&D in wind have been defined in cooperation with the partnership Megavind [11]. No new strategy reports were published in 2014, but a report on modeling the levelized cost of energy (LCOE) will be published at the European Wind Energy Association (EWEA) offshore conference in March 2015 [12].

The most recent strategy is Megavind's report *The Danish Wind Power Hub* from May 2013 [13]. Also in May 2013, Megavind released a roadmap for Megavind's Strategy for Offshore Wind Research, Development, and Demonstration, Denmark – Supplier of Competitive Offshore Wind Solutions [14].

4.1.1 Megavind report recommendations

In October 2014, Megavind published a report, *Increasing the Owners' Value of Wind Power Plants in Energy Systems with Large Shares of Wind Energy* [15]. The report includes recommendations for policymakers, industry, and research regarding important future initiatives for further development of and research in wind power. All the Megavind Strategies and reports can be downloaded from [11].

Key messages to policy makers: Policy makers in this context include politicians, energy system development planners, regulators, and transmission system operators. The report identifies the following needs.

1. Develop more international and larger energy markets
2. Further develop transmission grids to promote well-functioning energy markets
3. Provide economic incentives to promote the integration of energy systems in order to transfer demand from other energy systems to electricity, for

example, replace fossil fuels by electricity in the transportation sector
4. Shape markets so that it becomes more attractive for wind power to participate to all power system services
5. Continue public funding of new CAPEX projects as is done by public service obligation resources in Denmark today
6. Consider changing the tax on electricity to increase demand flexibility
7. Consider larger tenders to accelerate value chain maturation
8. Reduce the regulatory risks, which are presently disproportionately high compared to the market risks.

Key messages to industry: The following key messages are addressed to industry companies including owners, wind turbine manufacturers, and sub-suppliers:

1. It is important to have clear strategies and roadmaps on how to reduce the cost of electricity produced by wind power plants.
2. There is potentially a very high value in utilizing portfolio and cluster synergies, especially if the industry will cooperate.
3. The industry should aim to collaborate across the value chain.
4. The industry should communicate to potential investors that wind power is a sound, long-term investment in order to mitigate capital sourcing challenges.

Key messages to researchers: R&D is needed to support the development of the measures identified in this strategy:

1. Development of data mining techniques to handle the "big data" for the purpose of diagnostics and condition monitoring.
a. Studies of the technical and economic feasibility of: wind power joining markets (frequency control, balancing, ramping); use of probabilistic forecasts; and new market designs.
2. Development of new tools for economic assessment with special focus on higher resolution market models enabling studies of real-time balancing.
3. Technical studies of ancillary services from wind power plants: Uncertainties and values of ancillary services depending on service lifetime; new ancillary services from wind power plants allowing higher instantaneous penetration of wind power plants; dynamic modeling of ancillary services from wind power plants.
4. Cost reductions of O&M: use of condition monitoring (diagnostics); development of optimization tool(s).
5. Technical and economic feasibility studies of new electrical concepts: DC wind turbines and collection grids; low frequency AC transmission.
6. Power quality and harmonics: development of new test and assessment procedures to reduce costs for ensuring the necessary power quality; development of converter technologies and active control to mitigate the harmonic emission.

Statistics and information about supported energy research is published on a common website for all Danish Energy Research and Development Funding programs [16]. All funded projects within R, D&D can be found in the project gallery, as well as deadlines for applications and more information about the various programs. The latest annual report is "Energi14" with data from 2013 [17].

4.1.2 Public supported projects in 2014

In 2014 the following projects (Table 2) received grants with a total of 136 million DDK (18 million EUR; 22 million USD). The total research budget for the projects is more than 200 million DDK (27 million EUR; 33 million USD).

4.1.3 DTU wind energy tests [18]

Test Centre for Large Wind Turbines at Høvsøre

During the ten years existence of Høvsøre, innumerable tests have been performed on 19 different wind turbines, and the demand for new tests and measurements on turbines at Høvsøre will continue.

At Høvsøre, the wind conditions allow an almost uninterrupted, high wind speed coming from the North Sea that corresponds to conditions offshore. The flat terrain west of the test center means that the wind conditions at the turbines are very well defined. Wind speeds, wind direction, temperatures, and atmospheric pressure are being measured on all meteorological masts, and a few of the masts provide measurements at different heights. An average wind speed of 9.3 m/s has been measured at the height of 80 meters. All data is continuously gathered, and many are compared to measurements performed on the wind turbines.

National Test Centre for Large Wind Turbines at Østerild

In 2014, all test stands have been rented to companies. The two new tenants are EDF Enérgies Nouvelles from France and Vestas Wind Systems A/S from Denmark. Three new wind turbines were installed on test stands 2, 3, and 7 at the Test Centre, and one turbine on stand 6 was taken down. Siemens Wind Power has one turbine erected and a new one will be installed; Vestas Wind Systems installed two wind turbines.

4.1.4 LORC Lindoe Offshore Renewables Center [19]

Nacelle testing

LORC nacelle testing is a two test-dock design and a result of close cooperation between industry and academia. On one test dock, a mechanical test can be conducted, applying forces and moments on the nacelle main shaft, static as well as dynamic. This dock also offers Highly Accelerated Lifetime Testing (HALT). It enables customers to verify the expected quality level of the nacelle because it can simulate 20 years of operation in less than half a year depending on the size of the machine.

The other function tester dock tests the functionalities and performance of the nacelle. The function tester performs tests of the full nacelle and can include the hub where the blades are normally mounted. The absolute benefit of including the hub, and hence allowing the pitch system to be operational, is that it opens a range of opportunities for software testing. This is because communication signals and voltage supply can be used unmodified from the wind turbine controller inside the nacelle to the hub and rotor components.

LORC Component & Substructure Testing Centre

The LORC Centre focuses on mechanical and climatic testing of such areas as foundations' joints, experiments with new design rules, corrosion protection testing, etc. It was established in cooperation with industrial partner FORCE Technology.

Mechanical testing

With the aim of addressing practical challenges in the offshore wind turbine sector, the LORC Component & Substructure Testing Centre is establishing a strong basis for large-scale mechanical testing of materials, foundation structures, and components. The facility allows for static and dynamic testing and identification of structures' strength and durability.

The strong floor will have a number of generic load frames and actuators for static tension/compression, cyclic loading, bending,

Table 2. Supported Wind Energy R&D Projects in 2014				
English title	Company	Program Total budget: 1.40 (1.93) Grant: 0.70 (0.96)	Grant (million DKK; million EUR; million USD)	Project budget (million DKK; million EUR; million USD)
ERA-NET Plus - New European Wind Atlas	DTU Wind Energy	EUDP	15.0; 2.0; 2.4	26.4; 3.5; 4.3
Multi-level medium voltage converter	PowerCon	EUDP	15.7; 2.1; 2.5	29.8; 4.0; 4.9
Enhanced LIghtning effect TEsting capabilities for optimized wind turbine	Global Lightning Protection Systems A/S	EUDP	8.9; 1.2; 1.5	15.3; 2.1; 2.5
Offshore wind foundation node on an industrial scale	SIEMENS WIND POWER A/S	EUDP	8.5; 1.1; 1.4	21.3; 2.9; 3.5
Active filter functionalities for power converters	Aalborg Universitet	ForskEL	4.1; 0.6; 0.7	5.7; 0.8; 0.9
FORIDA TOWERS II - demomstration and further development	FORIDA DEVELOPMENT A/S	EUDP	7.7; 1.0; 1.3	15.5; 2.1; 2.5
Full scale basis test of wind turbines and their components Task 35	Danmarks Tekniske Universitet	EUDP	1.8; 0.2; 0.3	2.0; 0.2; 0.3
Cost-efficient lidar for pitch control	WINDAR PHOTONICS A/S	EUDP	8.6; 1.1; 1.4	13.0; 1.7; 2.1
Robot for automated assembly of bolts in the flange joints in wind turbines	Seagar ApS	EUDP	6.5; 0.9; 1.1	11.7; 1.6; 1.9
IEA Wind Task 29 Mexnext III	DTU Wind Energy	EUDP	1.1; 0.15; 0.17	1.3; 0.17; 0.21
IEA Task 30 Offshore Code Comparison Collaboration, Continued with Correlation	DTU Wind Energy	EUDP	1.31; 0.18; 0.21	1.83; 0.25; 0.30
DTU Wind Energy	Liftra ApS	EUDP	3.1; 0.42; 0.50	6.8; 0.91; 1.1
EUDP	Terma A/S	EUDP	4.2; 0.56; 0.7	6.9; 0.92; 1.1
1.31; 0.18; 0.21	DTU Wind Energy	EUDP	1.5; 0.2; 0.24	2.1; 0.28; 0.34
1.83; 0.25; 0.30	J Lemming Consulting	EUDP	0.13; 0.017; 0.05	0.15; 0.02; 0.024
Understanding the waves creates cheaper power from offshore wind turbines	DTU Wind Energy	Innovation Fund	20.2; 2.7; 3.3	24.9; 3.3; 4.0
The InnoMill project. Mobile robots to turn giant wind turbines into the profitable energy source of the future	DTU Mechanical Engineering, DAMRC research centre	Innovation Fund	13.5; 1.8; 2.2	24.7; 3.3; 4.0
Speedier production of long offshore wind turbine blades of a high quality	DTU Wind Energy	Innovation Fund	15.0; 2.0; 2.4	30.0; 4.0; 4.9

and torsion. The set-up includes modularized and flexible anchorage points for clamping and hydraulic equipment intended for static and dynamic loading.

- Loads and forces applied to simulate realistic offshore conditions
- Strong floor measures 20 x 9 meters
- 22 meters of 4-meter-high reaction walls
- Actuator capacities in the MN regime

Climatic testing

The LORC Component & Substructure Testing Centre establishes a climatic chamber for exposure of structures and components to varying climatic conditions, primarily low and high temperatures, temperature cycles, and corrosive environments. This can be used for the testing of cooling systems, transformers, hydraulic systems, generators, gears, etc.

- Very large components' functionality at extreme conditions like offshore
- Only commercially available climate chamber in Northern Europe with combination of temperature, humidity and corrosive environment
- Climate chamber: 14 x 8 x 8 meters
- Temperature: -38° C to +60° C
- Humidity control: 10% to 100% relative humidity
- Salt spray simulating offshore corrosive environment

4.2 Collaborative research

Danish energy policy objectives are achieved among other measures by taking part in international co-operation regarding R, D&D in energy technologies and public support is offered in order to promote that Danish companies and universities/research institutions take part in international co-operation regarding R, D&D in energy technologies.

International Energy Agency (IEA)

Within IEA, Denmark is participating in approximately 20 Implementing Agreements. The Energy Technology and Demonstration Program (EUDP) is offering support to the costs of participating in the Agreements. More information can be found at (http://www.iea.org/) and (http://www.ieawind.org).

EU programs

Danish companies and universities/research institutions very actively take part in EU R, D&D programs. Further information about Danish companies participating in EU programs may be found at (http://ufm.dk/en/) or on (http://cordis.europa.eu/fp7/).

Nordic Energy Research

Nordic Energy Research offers grants to projects and Danish companies, universities, and research institutions participate in

Figure 5. The HALT Tester of LORC Nacelle Testing - 6 degrees of freedom loads

projects supported by the program. The Nordic Energy Research Program is financed mainly by national programs and the Danish contribution is financed by EUDP. More information about the Nordic energy research program can be found at (http://www.nordicenergy.org/).

5.0 The Next Term

The next large offshore wind farms planned are Horns Rev III and Krieger's Flak, with a total capacity of 1,000 MW [1]. The detailed planning of these two projects and the near-shore projects, which were already described in earlier annual reports, has continued during 2014. The tendering process can be followed on The Danish Energy Agency's website (http://www.ens.dk/en/supply/renewable-energy/wind-power/offshore-wind-power) [7].

In total, three licenses are required to establish an offshore wind project in Denmark. The three licenses are granted by the Danish Energy Agency, which serves as a "one-stop-shop" for the project developer in relationship to the many interests connected to the establishment of offshore wind power projects:

1. License to carry out preliminary investigations
2. License to establish the offshore wind turbines (only given if preliminary investigations show that the project is compatible with the relevant interests at sea)
3. License to exploit wind power for a given number of years, and an approval for electricity production (granted if conditions in license to establish project are kept)

Horns Rev III and Krieger's Flak and the near-shore project follow the government tender procedure, while a number of other projects have been applied for though open door procedures. For more information see the above mentioned website at [7].

At the end of 2014 several offshore projects were in the planning process: 6 demonstration turbines at Frederikshavn; up to 14 demonstration turbines at Nissum Bredning; 20 turbines, 60–120 MW at Mejlflak; 400 MW at Horns Rev 3 (2020); 600 MW at Kriegers Flak; 200–320 MW at Omø Syd; 400 MW (50 MW demonstration turbines) at Near Shore offshore wind farms; and 120–240 MW at Jammerland Bugt.

The government plan includes new land-based wind turbines with a total capacity of 1,800 MW, expecting that over the same period a capacity of 1,300 MW will be dismantled. Energinet.dk's website [8] provides information on current projects.

References:

Opening photo: Giant new bench will test Vestas 8-MW offshore turbine (Photo credit: LORC)

[1] Accelerating green energy towards 2020, Energy Agreement from March 22, 2012, Danish Energy Agency. Item no. 978-87-7844-928-3

[2] Energy Policy in Denmark, Danish Energy Agency December 2012, Item no. 978-87-7844-959-7

[3] The Danish Government Energy policy report, Report from the Ministry of Climate, Energy and Building to the Danish Parliament, April 24, 2013 (In Danish).

[4] Oplæg om vindmølleudbygningen på land. Danish Energy Agency, January 22, 2014 (in Danish)

[5] Kommunernes muligheder for investering i vindmøller, Danish Energy Agency, June 19, 2014

[6] Nettilslutning af kystnære havmølleparker, Energinet.dk, March 2015. (Memo in English: Grid connection of nearshore wind farms by Danish Energy Agency March 3, 2015)

[7] The Danish Energy Agency web site, www.ens.dk and http://www.ens.dk/en/supply/renewable-energy/wind-power/offshore-wind-power

[8] Energinet.dk web site, www.energinet.dk 5

[9] Danmarks Vindmølleforening web site, www.dkvind.dk

[10] "Branchestatistik 2015" (in Danish). Danish Wind Industry Association, www.windpower.org

[11] Megavind. http://megavind.windpower.org/

[12] LCOE Calculator. http://megavind.windpower.org/megavind/lcoe_calculator_model.html

[13] Report from Megavind: The Danish Wind Power Hub, Strategy for Research, Development, and Demonstration, May 1013. http://ipaper.ipapercms.dk/Windpower/Megavind/Megavind_TheDanishWindPowerHub/

[14] Denmark – Supplier of Competitive offshore solutions. Roadmap for Megavind's Strategy for Offshore Wind Research, Development, and Demonstration http://ipaper.ipapercms.dk/Windpower/Megavind/MegavindOffshoreRoadmap/

[15] Increasing the Owners' Value of Wind Power Plants in Energy Systems with Large Shares of Wind Energy (2014) http://megavind.windpower.org/download/2445/Megavind_Value_of_Wind_Power_Plants.pdf

[16] Danish Energy Research. http://energiforskning.dk/en?language=en

[17] Energy14 The year in review: Research, Development, Demonstration (2013 data).
http://energi14.energiforskning.dk/sites/eudp-new.omega.oitudv.dk/files/energi14.pdf

[18] DTU Wind energy Research Facilities. http://www.vindenergi.dtu.dk/english/Research/Research-Facilities

[19] www.lorc.dk

Authors: Jørgen K. Lemming, J Lemming Consulting; and Hanne Thomassen, Danish Energy Agency, Denmark.