1.0 Overview

In 2013, 24.7% of Denmark’s energy consumption came from renewable sources, 36.9% from oil, 18.1% from natural gas, 17.7% from coal, and 2.2% from nonrenewable waste. The production from wind turbines alone corresponded to 33.2% of the domestic electricity supply in 2013, compared to 30.1% in 2012.

Wind power capacity in Denmark increased by 644 MW in 2013, bringing the total to 4,808 MW (Table 1). During the year, 692 MW of new turbines were installed, while 47.2 MW of old turbines were dismantled. Of the installed wind turbines, 350 MW were offshore, finishing the Køge Bay project Anholt. The largest rated turbines to be installed in 2013 were the 6-MW Siemens; six of these turbines were added onshore at Oesterild for production testing next to the one erected in late 2012.

2.0 National Objectives and Progress

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

This agreement implies a 12% reduction of gross energy consumption in 2020 in comparison to 2006; a share of 35% renewable energy in 2020; and 50% wind energy in Danish electricity consumption in 2020. The agreement includes a series of energy policy initiatives for 2012–2020, and the parties involved will take stock of the developments regularly. Before the end of 2018, further initiatives reaching beyond 2020 are to be discussed by the Parliament.

More details of the agreement can be found 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).

2.1 National targets

For wind power the agreement includes:

- 1,000 MW of large-scale offshore wind farms before 2020 (tendering process)
- Horns Rev III 400 MW (in operation in 2017–2020)
- Kriegers Flak 600 MW (in operations before 2020) – EU support to grid connection is 1.1 billion DKK (1.5 million EUR; 2.0 million USD)
- 450 MW of near-coast offshore installations (tendering process)
- 50 MW of offshore turbines for R&D
- 500 MW added capacity on land before 2020
- 1,800 MW of new generation on land including 1,300 MW for repowering.

2.2 Progress

As shown in Table 1 and Figure 1, the contribution from wind alone to domestic electricity production was 32.7% in 2013 compared to 29.9% in 2012.

The added wind capacity in Denmark in 2013 was 644 MW, bringing the total to 4,808 MW. This year, 692 MW were installed (342 MW added on land) and 48 MW were dismantled. The largest rated turbine to be installed in 2013 was the 6-MW Siemens. Six of these turbines were erected onshore at the Oesterild Testsite.
The Danish production from wind turbines alone corresponded to 33.2% of the domestic electricity supply in 2013, compared to 30.1% in 2012.

Table 1. Key National Statistics 2013: Denmark

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total installed wind capacity</td>
<td>4,808 MW</td>
</tr>
<tr>
<td>New wind capacity installed</td>
<td>644 MW</td>
</tr>
<tr>
<td>Total electrical output from wind*</td>
<td>11.1 TWh</td>
</tr>
<tr>
<td>Wind generation as % of national electricity demand</td>
<td>32.7%</td>
</tr>
<tr>
<td>Average capacity factor**</td>
<td>27.1%</td>
</tr>
<tr>
<td>Target: 50% of electricity demand from wind by 2020</td>
<td></td>
</tr>
</tbody>
</table>

* In 2013 the wind index was 93.4%  
**Average capacity factor based on production from turbines installed before January 1, 2013

Figure 1. Danish wind power capacity and share of domestic electricity supply from 1980–2013

Figure 2. Vestas 8-MW turbine at the Oesterild Testsite (Source: Vestas Wind Systems A/S)

2.3 National incentive programs

The key legislation related to renewable energy are: the Act on promotion of renewable energy (consolidated act 1330/2013), the Act on Electricity Supply (consolidated act 1329/2013), and the Act on the Danish TSO (consolidated act 1097/2011). Unofficial English translations of previous versions of the legislation are available (4). Each of the acts has issued a number of ordinances. The two most important in this context are: executive order no. 1063/2010 on grid connection of wind turbines and executive order no. 891/2011 on system operation and use of transmission grid.

the one installed there in late 2012. A new Vestas 8-MW turbine was certified for test in December 2013 and was also erected at the Oesterild Testsite in January 2014 (Figure 2).

A detailed history of installed capacity and production in Denmark can be downloaded from the Danish Energy Agency (4).

The environmental benefits due to the 2013 wind energy production, assume coal is being displaced, saved coal: 3,749,412 tons (337 g/kWh) and the following emissions avoided: CO₂: 8,633,660 tons (776 g/kWh); SO₂: 776 tons (0.07 g/kWh); NOX: 2,559 tons (0.23 g/kWh); particles: 223 (0.02 g/kWh); and Cinder/Ash: 589,670 tons (53 g/kWh) (5).
The Danish TSO that is responsible for operation of the electricity system has issued a number of regulations to be complied with for electricity generation equipment. They are all available online (6).

2.4 Issues affecting growth
The growth in offshore installation is a result of the installation of the Anholt Wind farm, where 350 MW (97 turbines) out of the planned 400 MW were installed in 2013. The growth on land (294 MW) resulted from government policies promoting more wind energy and from approval from local authorities of sites for large turbines on land.

Most of the new large wind turbines on land were raised in Jutland, especially in the western and northern parts.

During the year, 48 smaller and older wind turbines were dismantled, removing a capacity of approximately 48 MW. Fewer turbines have been dismantled in 2013 than in 2008–2011; the earlier replacement scheme expired in 2011.

3.0 Implementation
The Danish wind turbine industry association (7) publishes an annual report on the industry status and economic impact. The information in the latest annual report “Branchestatistik 2013” is for 2012 (8).

3.1 Economic impact
Turnover in the wind industry in Denmark decreased from 11.0 billion EUR (15.2 billion USD) in 2012 to 10.8 billion EUR (15.0 billion USD) in 2013. Total exports also experienced a decline from 7.0 billion EUR (9.7 billion USD) in 2012 to 6.5 billion EUR (9.0 billion USD) in 2012. The share of total sales in the same period was a little more than 60%. Hence, the Danish wind industry maintains activity levels with only a modest decline, indicating that the Danish wind industry remains competitive in the global and in particular the European wind market.

The employment level followed the decline in total exports and turnover. By the end of 2013, there were 27,490 employees in the Danish wind industry. This is a slight decrease compared to 2012 when there were 28,459 employees in the industry.

3.2 Industry status
Figure 3 shows the relative turnover, export, and employment in the Danish wind industry from 2006–2013.

The major Denmark-based manufacturers of large commercial wind turbines of one megawatt or larger are still Siemens Wind Power (formerly Bonus Energy A/S) and Vestas Wind Systems A/S.

3.3 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 the 2013 Anholt project (400 MW). Existing offshore wind farm locations in Denmark are described in the IEA Wind 2012 Annual Report.

The Anholt project was finished in 2013 with all 400 MW of capacity grid-connected and operating since June. More information can be found on DONG’s Web Site for Anholt (9).

At the end of 2013, 5,194 turbines with a capacity of 4,808 MW were in operation and the total production in the year was 11.1 GWh. The average capacity factor was 27.1% (average wind index 93.4%) for the turbines that have been in operation the whole year. The 870 MW of offshore wind farms alone counted for more than one-third of the production with a capacity factor of 40.8% for turbines in operation the whole year. The total penetration rose to nearly 33.1% in 2013 compared to 29.9% in 2012.

The average capacity of turbines installed is now over 2.7 MW (Figure 4), continuing the trend to larger machines over the last three to four years.

3.4 Wind energy costs
The average turnkey prices for wind in 2013 is estimated by EA Energi Analyse to be a little higher than in 2012 but still lower than 2008 (Figure 6).

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 between Energinet.dk, the Energy Technology Development and Demonstration Programme, the Danish Council for Strategic Research, the European Commission representation in Denmark, and the Danish Advanced Technology Foundation. An updated list of Danish-funded energy technology research projects is also available online (13).

4.1 National R, D&D efforts
The main priorities for R, D&D in wind have since 2007 been defined in cooperation with the partnership Megawind. The most recent strategy is Megawind’s report The Danish Wind Power Hub from May 2013 (10). Also in May 2013, Megawind released a roadmap for Megawind’s strategy for offshore wind R, D&D “Denmark–Supplier of Competitive Offshore Wind Solutions,” (11). All the Megawind Strategies can be downloaded (7).

The Danish Wind Power Hub strategy (10): Megawind’s vision for Denmark is to continue to develop its position as the hub of globally leading companies and research institutions within the field of wind energy and that these companies will be the first to deliver competitive wind energy on market terms in the dominating wind energy markets. To support the vision it is recommended to develop attractive innovation frameworks with a strong focus on long- and short-term R, D&D in the entire supply chain.

The Megawind report gives an overview of the current situation and provides seven key recommendations, including:

• A commonly agreed and accepted method for calculating and tracking the cost of energy from wind power
• A comprehensive strategy for increasing the ability of Danish research and educational institutions to contribute to maintaining Denmark as a global

Figure 3. Industry status (index 100 in 2006)
focus areas are as follows: forefront in offshore wind energy. The seven and bringing Danish competences to the driven down levelized cost of energy (LCOE) from offshore wind power plants and ensure that offshore wind energy becomes competitive with newly-built, coal-fired power by 2020. The LCOE in this roadmap should be understood as the societal cost of energy, i.e. the price society pays for one megawatt-hour produced.

The focus area “planning, consenting, policy framework, and site selection” relates to all other areas, and determines the outer boundaries of what is possible to achieve in terms of cost of energy. The remaining focus areas are the same focus areas as the former Megawind offshore strategy and these areas are most important to ensure ambitious reductions of LCOE. R, D&D in lowering construction and installation costs (CAPEX) includes four areas: wind turbines, foundations, electrical infrastructure, and assembly and installation. These areas are estimated to contribute significantly and equally to reducing life-time cost. Finally, with regard to the focus area of operation and maintenance, improvements in reliability and O&M strategies will reduce operational expenditure (OPEX) per megawatt-hour produced.

Statistics and information about supported Energy Research is published on the Web site (12). The latest annual report is “Energi13.” In 2013, 14 projects (Table 2) received grants for a total of 131 million DKK (17.6 million EUR; 24.2 million USD). The total public research budget for the 14 projects is at nearly 198 million DKK. (26.5 million EUR; 36.6 million USD) (13), (14).

**4.2 Test centers**

The onshore and offshore test and demonstration facilities at Østerild and the component test center LORC were described in more detail in earlier IEA Wind annual reports. Recent test center developments are described here.

DTU Wind Energy now has three wind turbine test sites in Denmark: Campus Riso, Roskilde; Havsoere Test site for Large Wind Turbines, Lemvig; and Test Center Østerild, Thisted (15). At Havsoere and Østerild, DTU Wind Energy has eight test stands. At the close of 2013, two test stands were available for rent at Test Centre Østerild. Vestas and Siemens also own four stands at Østerild. There are five test stands at Havsoere, where turbines up to 165-m blade tip height can be tested. Test Centre Østerild was established during 2012 and allows for wind turbines of up to 250-m tip height.

Several other test sites are in use. The old test site at Campus Riso is mainly used for specific research projects on components and for testing small wind turbines. DTU Wind also has a small component test center at Campus Riso. At the Lindoe Offshore Renewables Center, planning continues, and funding is now guaranteed. There will be two test beds for nacelles of up to 10 MW (16).

**4.3 Collaborative research**

The Danish Energy Agency takes care of Danish energy policy interests through its international, multilateral, and bilateral cooperation on energy and environment policy and research.

The Danish Energy Agency seeks to promote Denmark’s international position in the area of energy and to strengthen business and export opportunities for Danish energy technology and know-how. These activities take place in a number of different forums, including the EU, the European Energy Charter, the OECD, the IEA, the UN, the Nordic Council of Ministers, and IRENA, as well as with various bilateral cooperation partners including the Low Carbon Transition Unit’s programs in México, South Africa, and Vietnam.

Under the IEA R&D Collaboration, Denmark participates in many areas including Wind. In 2013, Denmark participated in 11 out of 12 tasks under the IEA Wind agreement. Most Danish participants come from research institutions, but also the industry is playing an active role.

**5.0 The Next Term**

The next large offshore wind farms planned are Horns Rev III and Krieger’s Flak, with a combined capacity of 1,000 MW (1). The planning of these projects was described in the **IEA Wind**
Pre-investigations and tendering procedure are on track for both wind farms. Locations are shown in Figure 6.

As mentioned above, the government’s plans up to 2020 now include 500 MW (total) near-shore offshore wind farms (including 50 MW for test sites). In November 2012, the results of surveys and negotiations were announced. In addition to the offshore farms at Horns Rev III and Kriegers Flak, six areas close to the coast have been selected for wind farms each as shown in Figure 6. In each area, it is possible to install up to 200 MW. The six areas will be tendered in competition with each other. In contrast to the large-scale offshore wind farms, the constructor will pay for grid connection up to the coast. From the coast, costs will be paid by the electricity consumers, through their general charges.

Regarding large offshore wind farms, the Danish Energy Agency will conduct a negotiated tendering procedure with prequalification and technical dialogue. Because the near-shore wind farms will be visible from shore, local joint ownership of 20% of each project will be offered to local ownership. This is similar to the approach used on land in order to maintain local support. If 30% local ownership is achieved, there will be a further price

Table 2. Supported Wind Energy R&D Projects in 2013

<table>
<thead>
<tr>
<th>Title</th>
<th>Company</th>
<th>Million EUR (million USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Online WASP for Small and Medium Size Wind Turbines</td>
<td>DTU Wind Energy Department</td>
<td>Total budget: 1.40 (1.93)</td>
</tr>
<tr>
<td></td>
<td>Period: 1/2014–1/2016</td>
<td>Grant: 0.70 (0.96)</td>
</tr>
<tr>
<td>Wind Load Simulator for Function and Durability Test of Wind Turbine</td>
<td>R&amp;D Consulting Engineers</td>
<td>Total budget: 1.50 (2.06)</td>
</tr>
<tr>
<td></td>
<td>Period: 12/2014–12/2016</td>
<td>Grant: 1.04 (1.43)</td>
</tr>
<tr>
<td>IEA Wind Task 27 – Small Wind Turbines at Turbulent Sites</td>
<td>DTU Wind Energy</td>
<td>Total budget: 0.13 (0.18)</td>
</tr>
<tr>
<td></td>
<td>Period: 4/2014–4/2016</td>
<td>Grant: 0.10 (0.14)</td>
</tr>
<tr>
<td>ODIN-Wind-Decommission of Offshore Wind Turbines</td>
<td>NIRAS A/S</td>
<td>Total budget: 1.56 (2.15)</td>
</tr>
<tr>
<td></td>
<td>Period: 9/2014–9/2016</td>
<td>Grant: 0.90 (1.24)</td>
</tr>
<tr>
<td>Single Blade Installation in High Wind Speeds</td>
<td>LIFTRA ApS</td>
<td>Total budget: 1.75 (2.41)</td>
</tr>
<tr>
<td></td>
<td>Period: 5/2013–5/2016</td>
<td>Grant: 1.03 (1.42)</td>
</tr>
<tr>
<td>Stiffening of Wind Turbine Blades – Mitigating Leading Edge Damages</td>
<td>BLADENA ApS</td>
<td>Total budget: 3.19 (4.40)</td>
</tr>
<tr>
<td>IEA Wind Task 33 – Reliability Data</td>
<td>DTU Wind Energy</td>
<td>Total budget: 0.13 (0.18)</td>
</tr>
<tr>
<td></td>
<td>Period: 9/2013–9/2015</td>
<td>Grant: 0.11 (0.15)</td>
</tr>
<tr>
<td>Integrated Solution for Maintenance and Repair of Wind Turbine Blades.</td>
<td>PP Techniq ApS</td>
<td>Total budget: 0.80 (1.10)</td>
</tr>
<tr>
<td></td>
<td>Period: 10/2014–10/2014</td>
<td>Grant: 0.36 (0.50)</td>
</tr>
<tr>
<td>Extreme Winds and Waves for Offshore Turbines</td>
<td>DTU Wind Energy</td>
<td>Total budget: 1.28 (1.76)</td>
</tr>
<tr>
<td></td>
<td>Period: 2013</td>
<td>Grant: 0.67 (0.92)</td>
</tr>
<tr>
<td>Management of Seabed and Wind Farm Interaction</td>
<td>DHI</td>
<td>Total budget: 2.01 (2.77)</td>
</tr>
<tr>
<td></td>
<td>Period: 2013</td>
<td>Grant: 0.74 (1.02)</td>
</tr>
<tr>
<td>ABYSS - Advancing BeYond Shallow waterS – Optimal Design of Offshore</td>
<td>DTU Wind Energy,</td>
<td>Total budget: 3.69 (5.08)</td>
</tr>
<tr>
<td>Wind Turbine Support Structures</td>
<td>Period: 2014–2017</td>
<td>Grant: 2.9 (4.0)</td>
</tr>
<tr>
<td>Wind2050 – Multidisciplinary Study on Local Acceptance and Development</td>
<td>DTU Management Engineering,</td>
<td>Total budget: 3.16 (4.35)</td>
</tr>
<tr>
<td>of Wind Power Projects</td>
<td>Period: 2014–2017</td>
<td>Grant: 2.67 (3.68)</td>
</tr>
<tr>
<td>UniTe – Unified Testing Procedures for Wind Turbines Through Inflow</td>
<td>DTU Wind Energy,</td>
<td>Total budget: 2.60 (3.28)</td>
</tr>
<tr>
<td>HyDrive – Hydrostatic Drive Train Transmission for Renewable Energy</td>
<td>Aalborg University</td>
<td>Total budget: 3.32 (4.57)</td>
</tr>
<tr>
<td>Applications</td>
<td>Period: 2014–2019</td>
<td>Grant: 2.57 (3.54)</td>
</tr>
</tbody>
</table>

2011 Annual Report. Pre-investigations and tendering procedure are on track for both wind farms. Locations are shown in Figure 6.

As mentioned above, the government’s plans up to 2020 now include 500 MW (total) near-shore offshore wind farms (including 50 MW for test sites). In November 2012, the results of surveys and negotiations were announced. In addition to the offshore farms at Horns Rev III and Kriegers Flat, six areas close to the coast have been selected for wind farms each as shown in Figure 6. In each area, it is possible to install up to 200 MW. The six areas will be tendered in competition with each other. In contrast to the large-scale offshore wind farms, the constructor will pay for grid connection up to the coast. From the coast, costs will be paid by the electricity consumers, through their general charges.

Regarding large offshore wind farms, the Danish Energy Agency will conduct a negotiated tendering procedure with prequalification and technical dialogue. Because the near-shore wind farms will be visible from shore, local joint ownership of 20% of each project will be offered to local ownership. This is similar to the approach used on land in order to maintain local support. If 30% local ownership is achieved, there will be a further price.
supplement of 0.13 EUR/kWh (0.18 USD/kWh) for the full subsidy period.

The government plan includes installation of new onshore wind turbines with a total capacity of 1,800 MW. It is expected that over the same period a capacity of 1,300 MW will be dismantled. Energinet.dk’s website (6) provides information on current projects. Compiled at the end of 2013, and excluding test turbine projects, new onshore wind projects under way correspond to approximately 600 MW. It may take a long period of planning before these wind turbine projects can be started and the turbines connected to the grid. Some of these projects may not obtain final approval.

References:

Opening photo: Anholt Wind Farm. Credit: Wind Power Works/KeenPress


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