# IEA Wind TCP

## 2015 Annual Report

Executive Committee of the Implementing Agreement for
Co-operation in the Research, Development, and Deployment of Wind
Energy Systems of the International Energy Agency*

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**Front cover photo:** Wind turbine in Peuchapatte (Credit: SwissEole)

*Also known as the IEA Wind Technology Collaboration Programme (TCP)

# Message From the Chair

Wind-generated electricity met close to 4% of the world's electricity demand in 2015—a record-setting year with more than 63 GW of new wind power capacity installed. Worldwide capacity stands at about 433 GW of wind power capacity and more than 85% (368.5 GW) resides in the 22 countries participating in the International Energy Agency Wind (IEA Wind) Technology Collaboration Programme (TCP). Illustrating wind energy's significance in IEA Wind member countries, Portugal met 100% of its electricity needs with renewables for four consecutive days in May 2016—the same timeframe as IEA Wind's 77th Executive Committee meeting in Lisbon.

Wind power was the leading source of new electricity generating capacity in Europe, the United States and Canada in 2015, and the second largest in China. Denmark set a new record by meeting more than 40% of electric demand with wind-generated electricity in 2015; Ireland, Portugal, and Spain each met close to 20%. Offshore wind also had a very strong year with 12 GW operating in 13 countries at the close of 2015, including the 3.4 GW added in 2015. Wind power system performance and reliability continues to improve and costs are becoming more competitive.

The *IEA Wind 2015 Annual Report* documents the activities and accomplishments of our member governments and organizations, as well as the development and deployment efforts of the 15 collaborative research tasks. IEA Wind Tasks focus on sharing the latest technologies and best practices and overcoming specific wind energy development barriers faced by our member countries. Two new tasks were approved in 2015: Task 36 Forecasting for Wind Energy and Task 37 Wind Energy Systems Engineering: Integrated Research, Design, and Development.

Continued growth in wind energy's contribution to electricity supply will depend on solving the critical technology and deployment challenges of the future. It is with great satisfaction and confidence that I hand the Chair position of IEA Wind TCP to Ignacio Marti, Innovation & Research Director of the UK-based Offshore Renewable Energy (ORE) Catapult. It has been an honor to Chair IEA Wind and I know the good work will continue under Ignacio's leadership.

JMAhlgrimm

**Jim Ahlgrimm**
Chair of the Executive Committee, 2013–2015

Ignacio Marti, Chair-Elect of the Executive Committee

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# 1 Executive Summary

## 1.0 Introduction

**Globally, a record of more than 63 GW of wind power was added in 2015, reaching a total of about 433 GW installed capacity [1, 2]. Wind power was the leading source of new power generating capacity in Europe and the United States and Canada in 2015, and the second largest in China. The offshore wind sector had a strong year with an estimated 3.4 GW connected to grids, mostly in Europe, for a world total exceeding 12 GW. Wind-generated electricity met close to 4% of the world's electricity demand in 2015 [1]. Wind power is playing a major role in meeting electricity demand in an increasing number of countries, including Denmark (where wind reached a new record of meeting more than 40% of demand); Portugal, Spain, and Ireland (close to 20%); Germany (close to 15%); and Sweden and the United Kingdom (UK) (close to 10% of demand in 2015). New investors worldwide are embracing wind energy as a profitable and growing sector which is considered low risk.**

**About 85% of the world's wind generating capacity, and nearly all of the capacity offshore, resides in the 22 countries participating in the International Energy Agency Wind (IEA Wind) Technology Collaboration Programme (TCP). IEA Wind is an international co-operation that shares information and research activities to advance wind energy deployment. The IEA Wind member countries added more than 51 GW of capacity in 2015, which is more than 81% of the record-setting worldwide market growth for the year (63 GW). In the IEA Wind countries, the 368.5 GW of wind generating capacity operating in 2015 generated almost 700 TWh and met 4.8% of the total electrical demand (Tables 1–4). Largest non-IEA Wind countries are India (25 GW), Brazil (nearly 9 GW), Poland (5 GW), Turkey (5 GW), and Australia (4 GW) [2].**

**This *IEA Wind 2015 Annual Report* contains chapters from each participating country and from WindEurope (formerly the European Wind Energy Association) and the European Commission (EC) (the executive of the European Union [EU]). The countries report how much wind energy they have deployed, how they benefit from wind energy, and how their policies and research programs will increase wind power's contribution to the world energy supply. This annual report also presents the latest research results and plans of the 15 co-operative research activities (tasks) that address specific issues related to wind energy development.**

**This Executive Summary presents highlights and trends from the chapters about each member country and research task, as well as compiled statistics for all countries. Data reported in previous IEA Wind documents (IEA Wind 1995–2014), are included as background for discussions of 2015 events. Several countries also report the decommissioned capacity from old turbines and this has been taken into account in the capacity totals. The website (www.ieawind.org) contains archived searchable documents dating back to the very beginning of the IEA Agreement in 1977.**

**The industry had another strong year, and most top turbine manufacturers broke their own installation records [1]. To meet rising demand, new factories opened or were under construction around the world. Challenges included lack of transmission infrastructure and curtailment of wind generation, lengthy and costly permitting processes and public acceptance. The main risk for wind energy is the lack of stable and long-term energy policies.**

## 2.0 National Objectives and Progress

IEA's updated *Technology Roadmap for Wind Energy* [3] targets a goal of 15–18% of global electricity coming from wind power by 2050. In 2015, wind energy supplied 3.7% of global electricity [1]. Wind power makes constant progress towards this goal, by adding roughly 0.5 percentage points yearly.

IEA Wind member governments establish national targets for renewable energy and wind energy (Table 4), design market mechanisms and energy policies (Table 9), and fund research and development (R&D) programs to help reach these targets (Table 15). Their reasons for supporting wind energy include reducing greenhouse gas emissions and other pollutants, increasing employment and economic development, building a domestic industry, contributing to domestic energy supply, and replacing nuclear energy.

### 2.1 National targets

Most IEA Wind member countries have targets for increasing the amount of renewable energy or low-carbon energy in the electrical generation mix. These targets are embedded in legislation, appear in roadmap documents, or have been announced by elected officials. The targets often reflect goals in greenhouse gas emission reduction. Some countries have specific goals or targets for wind energy in particular. Table 4 shows the 2015 values compared to the wind targets for each country: power capacity (MW), contributions to electricity supply (TWh), or contribution to electricity demand (%).

EU has a target of a 20% renewable energy contribution to total energy consumption (transport, heat and electricity) by 2020. This target has been allocated to member states. Member states were required to identify national allocations of the target across the three demand categories and some countries have set specific wind energy targets. Some countries have set higher targets (Austria and Denmark). The EU has set a further target for 2030 of at least 27% renewable energy contribution to energy demand. However, this target has not been allocated to member countries.

In both the United States and Canada there have been no official targets at the national level, even if most of the states and provinces have targets. However, the government of Canada announced plans in May 2015 to reduce the nation's greenhouse gas emissions by 30% below 2005 levels by 2030. The United States announced that it will reduce carbon emissions 26–28% below 2005 levels in 2025 and the *Wind Vision* report published by the U.S. government presents a scenario where 10% of the nation's electricity would be generated by wind power in 2020, 20% in 2030, and 35% in 2050.

Many countries are currently preparing targets and policies for beyond 2020. In 2015, new policy papers or targets were released in China, Denmark, France, Ireland, and the Netherlands. In Japan, a new policy paper included 1.7% of electricity from wind power in 2030. This would mean adding 7 GW in 15 years, in addition to the 3 GW installed now.

China has set targets for wind power and caps for coal power to achieve government's target of having about 15% and 20% of non-fossil fuels in total primary energy consumption by 2020 and 2030.

**Table 1. Key Statistics of Wind Energy 2015**

| | IEA Wind Member Countries | Global Statistics [1,2] |
|---|---|---|
| Total installed capacity (land-based and offshore) | 368.5 GW | 432.9 GW |
| Total offshore wind capacity[a] | 12.1 GW | 12.1 GW |
| Total new wind capacity installed | 51.6 GW | 63.4 GW |
| Total annual output from wind | 696.9 TWh | not available |
| Wind-generated electricity as a % of national electric demand | 4.8% | 3.7% |

[a] In the International Electrotechnical Commission (IEC) Standard Document, IEC 61400-3 (Offshore Wind Turbines), offshore wind turbine is defined as a "wind turbine with a support structure which is subject to hydrodynamic loading." For this report, wind turbines standing in lakes, rivers, and shallow and deep waters are considered offshore.

### 2.2 Progress

#### 2.2.1 Capacity increases

A record 51.62 GW of net wind capacity was added in 2015 by the IEA Wind member countries; 23% more than the 40.68 GW added in 2014 (Figure 1). This added capacity was 81% of the global wind market for 2015, which was also a record at 63.5 GW [2]. In Europe and the United States, the 2015 wind installations represented more capacity than any

**Table 2. National Statistics of the IEA Wind Member Countries 2015**

| Country | Total Installed Wind Power Capacity | Annual Net Increase in Capacity[a] | Wind-based Electrical Energy | National Demand on Electrical Energy | National Electricity Demand Met by Wind Energy[b] |
|---|---|---|---|---|---|
| | (megawatts [MW]) | (MW) | (terawatt-hours [TWh]) | (TWh) | (%) |
| Austria | 2,409 | 323 | 5.2 | 60.0 | 8.7 |
| Belgium | 2,229 | 270 | 5.5 | 81.2 | 6.7 |
| Canada | 11,205 | 1,506 | ***28.5*** | ***575.0*** | ***5.0*** |
| China | 144,901 | 30,293 | 186.3 | 5,654.4 | 3.3 |
| Denmark | 5,070 | 83 | 14.1 | 33.6 | 42.0 |
| Finland | 1,005 | 374 | 2.3 | 83.0 | 2.8 |
| France | 10,308 | 932 | 20.2 | 476.3 | 4.2 |
| Germany | 44,946 | 5,818 | 88.0 | 600.0 | 14.7 |
| Greece[c] | 2,152 | 172 | ***3.5*** | ***49.3*** | ***7.1*** |
| Ireland | 2,455 | 244 | 6.6 | 29.2 | 22.6 |
| Italy | 8,942 | 295 | 14.6 | 315.2 | 4.6 |
| Japan | 3,038 | 244 | 5.2 | 953.5 | 0.6 |
| Korea | 835 | 223 | 1.1 | 546.0 | 0.2 |
| México[c] | 3,073 | 714 | 7.3 | ***286.0*** | ***3.2*** |
| Netherlands | 3,376 | 511 | 7.5 | 118.4 | 6.3 |
| Norway | 873 | 17 | 2.5 | 130.4 | 1.9 |
| Portugal | 5,033 | 80 | 11.6 | 50.4 | 23.0 |
| Spain | 22,988 | 0 | 47.7 | 245.0 | 19.5 |
| Sweden | 6,029 | 604 | 16.6 | 136.0 | 12.2 |
| Switzerland | 60 | 0 | 0.1 | 56.9 | 0.2 |
| UK | 13,614 | 806 | 40.4 | 338.7 | 11.9 |
| United States | 73,992 | 8,114 | 190.1 | 3,724.5 | 5.1 |
| **Totals** | **368,534** | **51,624** | **705.0** | **14,543.0** | **4.8** |

***Bold italic*** indicates estimates

[a] Net increase in capacity = capacity installed minus capacity decommissioned

[b] Share of wind energy from total demand: Percent of national electricity demand from wind = (wind generated electricity / national electricity demand) × 100

[c] Global Wind Energy Council [2] and ENTSO-E [8]

other generation technologies. Wind energy has been Canada's largest source of new electricity generating capacity for five years.

- China installed a record of over 30 GW in one year. Three other countries added more than one GW in one year: the United States (8.1 GW), Germany (5.8 GW), and Canada (1.5 GW).
- Germany installed/connected a record of 2.3 GW new offshore wind and achieved a record with total installed wind power of 5.8 GW. Other record installations were achieved in Finland, Korea, and the Netherlands.
- Eleven countries installed more capacity in 2015 than in 2014: China, Denmark, Finland, Germany, Greece, Italy, Japan, Korea, México, the Netherlands, and the United States [4].
- Fifteen countries each added more than 200 MW of new capacity.
- Four countries increased their cumulative capacity by more than 20% in 2015: Finland (60%), Korea (35%), México (30%), and China (26%) (Table 5).
- In the EU, wind power installations represented 44% of all new power capacity installations.

By the end of 2015, seven IEA Wind member countries had more than 10 GW of installed capacity: China (145 GW), the United States (74 GW), Germany (45 GW), Spain (23 GW), the UK (13.6 GW), Canada (11 GW), and France (10 GW). China exceeded the cumulative capacity of Europe.

As a whole, capacity has increased in the IEA Wind member countries from less than 5 GW in 1995 to more than 368 GW in 2015 (Figure 1). The added capacity in eleven countries more than offset the reduced annual installations in ten countries compared to the previous year.

Several countries also report dismantled old capacity. In Denmark, 42 MW (112 turbines) were dismantled, while 233 MW (621 new turbines) were installed. Denmark has seen a total of 2,847 turbines with a capacity of 513 MW being dismantled between 1987 and 2015. The average age of dismantled turbines has been 17 years. Many sites have seen *repowering*, the replacing of smaller, older turbines with larger-capacity machines. This is a way to increase land-based capacity without significantly increasing the land area used. In Germany, 484 MW (176 turbines) of repowering was reported in 2015. This is down from the 1,148 MW in 2014 because the repowering bonus was withdrawn and repowering was redefined as a wind turbine that is directly replaced by a newer wind turbine.

Wind power capacity is mostly represented by large turbines of 1 MW or greater. However, installation of individual, small wind turbines continues in most countries at homes, farms, and small industrial users. In the United States, distributed capacity totals 934 MW, representing more than 75,000 turbines, of which 28 MW (more than 1,700 turbines) were installed in 2015. In Denmark, 2015 saw 545 new turbines installed that were rated below 25 kW. Denmark's new feed-in premium tariffs for small wind turbines came into force in 2015 and the data register for small turbines was updated. In Italy, smaller size turbines (<200 kW) received easier permitting and better market conditions and at the end of 2015 a total of 50 MW (2,000 turbines) were operating.

**Table 3. Countries with more than 1 GW installed at the end of 2015**

| Country | Total Installed Wind Power Capacity (MW) |
|---|---|
| China | 144,901 |
| United States | 73,992 |
| Germany | 44,946 |
| India[a] | 25,088 |
| Spain | 22,988 |
| UK | 13,614 |
| Canada | 11,205 |
| France | 10,308 |
| Italy | 8,942 |
| Brazil[a] | 8,715 |
| Sweden | 6,029 |
| Poland[a] | 5,100 |
| Denmark | 5,070 |
| Portugal | 5,033 |
| Turkey[a] | 4,694 |
| Australia | 4,187 |
| Netherlands | 3,376 |
| México[a] | 3,073 |
| Japan | 3,038 |
| Romania | 2,976 |
| Ireland | 2,455 |
| Austria | 2,409 |
| Belgium | 2,229 |
| Greece | 2,152 |
| South Africa | 1,053 |
| Finland | 1,005 |
| **Rest of the world** | 14,304 |
| **Total** | **432,883** |
| European Union | 141,600 |

***Bold italic*** indicates estimates

[a] Numbers from GWEC [2]

### 2.2.2 Wind-based Electrical Energy

In IEA Wind member countries, wind power *capacity* increased by 51.5 GW, 17% in 2015 and electricity *production* from wind increased by 98.1 TWh or 16% over 2014. In 2015, combined wind-based electrical energy production met 4.8% of the combined national electrical demand of the IEA Wind countries, compared to 4.1% in 2014.

Records in provided energy were made in 2015. In Germany, the 53% increase from 2014 resulted in a 15% share coming from wind energy. The United States generated more energy from wind than any other country: 190 TWh. Finland more than doubled the wind power production and Sweden increased by 43%. Canada, Ireland, and the Netherlands each increased 29%. The UK (28%), México (28%), and China (21%) also made great increases in their wind power production.

The wind resource for a given year plays a major role in the resulting electricity production statistics. For this reason, considering wind indexes along with production numbers is becoming more common. These indexes are based on a five- to fifteen-year average wind resource (depending on the country) and reflect the wind power production. In 2015, more IEA Wind member countries reported wind resource levels higher than the average than lower than average (Table 6).

Several countries have also reported increased productivity: the turbine designs with larger rotors for same installed capacity mean more generation per installed power. The trend of taller turbines reaching better wind resource is still continuing.

An issue that reduces available wind power is curtailment—reducing generation of wind power plants in times of surplus generation from the electrical grid point of view. This is affecting wind-based electrical energy production especially in China, and to some extent in Ireland.

The share of wind energy providing for the total electricity consumption increased in 2015 in all countries except in Italy, Portugal, and Spain. In these countries the additions to wind power capacity was low and the wind resource was not as good as in 2014. In Korea and Switzerland the share remained constant (Table 7). National electricity demand is affected by economic growth, weather, and energy conservation policies, while wind power production mainly depends on the amount of wind power capacity installed, wind resource, and curtailment.

# 1 Executive Summary

**Table 4. Targets Reported for IEA Wind Countries**

| Country | Official Target Renewable Energy Sources (RES) | Official Target Wind | 2015 Total Wind Capacity (GW), Annual share of demand (%), or Annual Production (TWh) |
|---|---|---|---|
| Austria | 34% of final energy consumption by 2020 | 3 GW | 2.4 GW |
| Belgium | 13% of final energy consumption by 2020 | Offshore wind 2.7 GW and land-based wind 3 GW in 2020 | Offshore: 0.7 GW<br>Land-based: 1.5 GW |
| Canada | not available for federal level; targets in provinces | not available for federal level; targets in provinces | 11.2 GW |
| China | 15% and 20% of non-fossil fuels in total primary energy consumption by 2020 and 2030 | 250 GW at a price equal to that of thermal electricity by 2020; 460 TWh generated by wind in 2020 | 144.9 GW<br>186.3 TWh |
| Denmark | 35% in 2020 and 100% in 2050 | 50% of electricity by 2020 | 42% |
| European Union | 20% of final energy consumption by 2020 | 208 GW by 2020 | 141.6 GW |
| Finland | 38% of final energy consumption by 2020 | 6 TWh/yr in 2020 | 2.3 TWh |
| France | 23% of final energy consumption in 2020; 40% of electricity in 2030 | 24,800—29,000 MW (including 3 GW offshore) installed by 2023 | Land-based: 10.3 GW<br>Offshore: 0.0 GW |
| Germany | 30% (2030) 45% (2040) 60% (2050) of gross energy demand; 40-45% (2025) 55-60% (2035) 80+% (2050) of gross electricity demand | Land-based: 2.8-2.9 GW gross/yr;<br>Offshore: 7.7 GW by 2020 and 15 GW by 2030 | Land-based: 41.7 GW<br>Offshore: 3.3 GW |
| Greece | 40% of electricity by 2020 | 7.5 GW by 2020 | 2.2 GW |
| Ireland | 16% of final energy consumption and 40% of electricity by 2020 | No target but 3.5 GW estimated contribution to 2020 RE target | 2.5 GW |
| Italy | 17% of final energy consumption by 2020 | 12 GW land-based,<br>0.68 GW offshore by 2020 | Land-based 8.9 GW<br>Offshore 0 GW |
| Japan | 21 to 23% of electricity in 2030, in 4th Strategic Energy Plan METI 2014 | 10 GW in 2030, in Long-term Energy Supply and Demand Outlook METI 2015 (1.7%) | 3.0 GW |
| Korea | 3.0% of electricity in 2015, 10 % in 2024 | 0.9% of electricity by 2020 | 0.2% |
| México | 35% by 2024 | 12 GW by 2024 | 3.1 GW |
| Netherlands | 14% of final energy consumption by 2020 | 6 GW land-based by 2020<br>4.45 GW offshore by 2023 | Land-based 3.0 GW<br>Offshore 0.4 GW |
| Norway | 67.5% of final energy consumption by 2020; +26.4 TWh/yr new renewable electricity by 2020 with Sweden | --- | 2.5 TWh |
| Portugal | 31% of final energy consumption by 2020 | 5.3 GW land-based,<br>0.027 GW offshore by 2020 | Land-based: 5.0 GW<br>Offshore: 0.002 GW |
| Spain | 20% of final energy consumption by 2020 | Estimated for wind 29.5 GW, 6.4 GW more by 2020 | 23 GW |
| Sweden | 50% of final energy consumption by 2020 | Planning framework of 30 TWh by 2020: 20 TWh land-based, 10 TWh offshore | 16.6 TWh |
| Switzerland | Increase generation by 22 TWh by 2050 | 4.0 TWh/yr by 2050 (0.6 TWh by 2020, 1.5 TWh by 2035) | 0.1 TWh |
| UK | 15% of final energy consumption, 30% of electricity by 2020 | No specific target but forecast of 20 GW by 2020 | 13.6 GW |
| United States | COP21 agreement: Reduce carbon emissions 26% to 28% below 2005 levels by 2025 | Goals from *Wind Vision* report: Wind energy to supply 10% of the country's electricity by 2020, 20% by 2030, and 35% by 2050 | 5.1% |

--- = No official target available

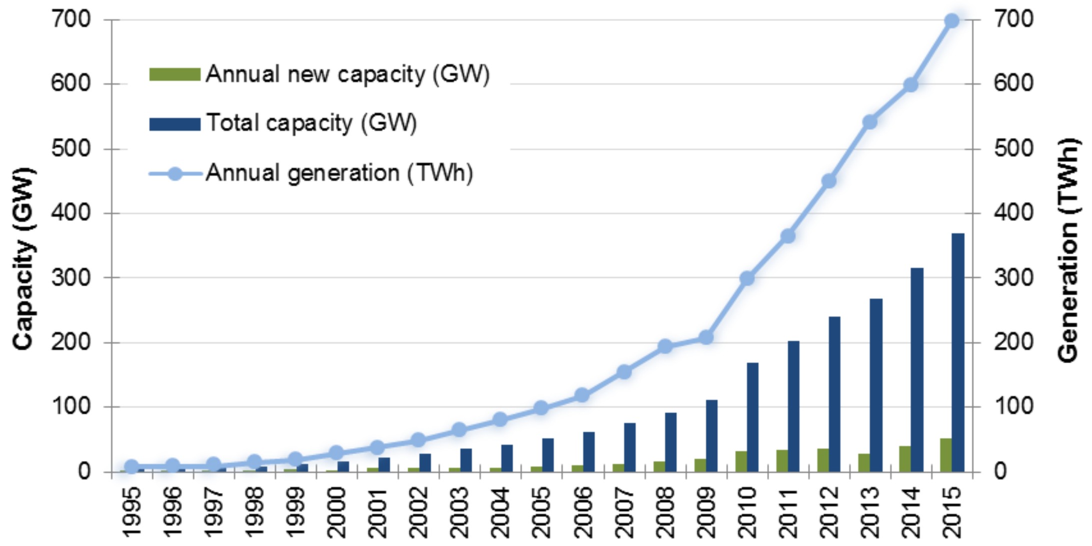

Figure 1. Annual new capacity (net), cumulative capacity, and electricity production for IEA Wind member countries, 1995–2015 (Note: China is first represented in 2010; France in 2014; and Belgium in 2015)

**Table 5. Wind Power Capacity Increases**

| Country | Cumulative Capacity End of 2014 (MW) | 2015 Added Capacity (MW) | Increase (%)[a] |
|---|---|---|---|
| Finland | 1,005 | 374 | 60% |
| Korea | 835 | 223 | 35% |
| México[b] | 3,073 | 714 | 30% |
| China | 144,901 | 30,293 | 26% |
| Netherlands | 3,376 | 511 | 19% |
| Canada | 11,205 | 1,506 | 16% |
| Austria | 2,409 | 323 | 15% |
| Germany | 44,946 | 5,818 | 15% |
| Belgium | 2,229 | 270 | 14% |
| United States | 73,992 | 8,114 | 12% |
| Sweden | 6,029 | 604 | 11% |
| Ireland | 2,455 | 244 | 11% |
| France | 10,308 | 932 | 10% |
| Japan | 3,038 | 244 | 9% |
| Greece[b] | 2,152 | 172 | 9% |
| UK | 13,614 | 806 | 6% |
| Italy | 8,942 | 295 | 3% |
| Norway | 873 | 17 | 2% |
| Denmark | 5070 | 83 | 2% |
| Portugal | 5033 | 80 | 2% |
| Spain | 22 988 | 0 | 0% |
| Switzerland | 60 | 0 | 0% |

***Bold italic*** indicates estimates
[a] % increase = (added capacity 2015÷capacity in 2014) x 100
[b] Numbers reported by GWEC [2]

Denmark set the new world record by meeting 42% of annual national electricity demand from wind energy in 2015. Several countries reported new records for monthly, weekly, and daily shares of wind energy meeting electricity demand. Wind energy covered more than 100% of the electricity demand in Portugal for the first time in December 2015 for more than three hours. In Spain, a new record of 70% of electricity demand was supplied by wind energy during one hour and wind generation was the main source of generation during the month of February. In Denmark, wind energy has been meeting more than 100% of demand during several hours for many years.

### 2.2.3 Offshore wind progress and plans

Nearly all of the world's offshore wind is operating in IEA Wind countries. Offshore wind power plants totaling 12 GW were operating in 13 countries at the close of 2015 and 3.4 GW was added in 2015 (Table 8). Offshore wind is seen as a very important area for expansion of wind development in countries where the land-based resource is not enough to fulfil the targets for renewables.

Several countries have set specific targets for offshore wind deployment (Table 4) and are making good progress. In the UK, a record of 5.1% of electricity was generated by offshore wind in 2015. The UK is the leader in global cumulative offshore wind capacity

**Table 6. Reported Wind Resource for 2015 Compared to Average**

| **High Wind** Country (index %) | **Average Wind** Country (index %) | **Low Wind** Country (index %) |
|---|---|---|
| Belgium<br>Denmark (114%)<br>Finland (128%)<br>Germany<br>Ireland<br>Norway (113%)<br>UK (104%) | Netherlands (102%)<br>Portugal<br>United States[a] | China<br>Spain (95%) |

The average wind year = 100%
[a] Regional resources vary across the continent in any year

**Table 7. Contribution of Wind to National Electricity Demand 2010–2015**[a]

| Country | National Electricity Demand (TWh) 2015 | 2010 (%) | 2011 (%) | 2012 (%) | 2013 (%) | 2014 (%) | 2015 (%) |
|---|---|---|---|---|---|---|---|
| Denmark | 33.6 | 21.9 | 28.0 | 29.9 | 32.7 | 39.1 | 42.0 |
| Portugal | 50.4 | 17.0 | 18.0 | ***20.0*** | 23.5 | 24.0 | 23.0 |
| Ireland | 29.2 | 10.5 | 15.6 | ***14.5*** | ***16.3*** | 18.3 | 22.8 |
| Spain | 245.0 | 16.4 | 16.3 | 17.8 | 20.9 | ***20.4*** | 19.5 |
| Germany | 600.0 | 6.1 | 8.1 | 8.3 | 8.5 | 9.6 | 14.7 |
| Sweden | 136.0 | 2.6 | 4.4 | 5.0 | 7.0 | 8.0 | 12.2 |
| UK | 332.6 | 2.6 | 4.2 | 5.0 | 5.0 | 9.0 | 11.9 |
| Austria | 60.0 | 3.0 | 3.6 | 5.0 | 5.8 | 7.2 | 8.7 |
| Greece[b] | 51.2 | 4.0 | 5.8 | ***5.8*** | ***5.8*** | ***6.1*** | ***7.1*** |
| Belgium | 81.2 | 1.4 | 2.6 | 3.3 | 4.4 | 6.4 | 6.7 |
| Netherlands | 118.4 | 4.0 | 4.2 | 4.1 | 4.7 | 4.8 | 6.3 |
| United States | 3,724.5 | ***2.3*** | ***2.9*** | ***3.5*** | ***4.1*** | ***4.4*** | 5.1 |
| Canada | 575.0 | ***1.8*** | ***2.3*** | ***2.8*** | ***3.1*** | ***3.8*** | ***5.0*** |
| Italy | 315.2 | ***2.6*** | ***3.0*** | ***4.0*** | ***4.7*** | ***4.9*** | 4.6 |
| France | 476.3 | --- | 2.2 | 3.1 | 3.3 | 3.6 | 4.2 |
| China | 5,654.4 | 1.2 | 1.6 | 2.0 | 2.6 | 2.8 | 3.3 |
| México[b] | 286.0 | ***0.6*** | ***0.6*** | ***1.2*** | ***1.5*** | ***2.0*** | ***3.2*** |
| Finland | 83.0 | 0.3 | 0.6 | 0.6 | 0.9 | 1.3 | 2.8 |
| Norway | 130.4 | 0.7 | 1.0 | 1.1 | 1.4 | 1.7 | 1.9 |
| Japan | 953.5 | 0.4 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 |
| Korea | 546.0 | 0.2 | 0.2 | 0.2 | ***0.2*** | ***0.2*** | 0.2 |
| Switzerland | 56.9 | 0.05 | 0.1 | 0.1 | ***0.2*** | ***0.2*** | 0.2 |
| **Overall of IEA Wind Countries** | | ***2.3*** | ***2.8*** | ***3.3*** | ***3.8*** | ***4.1*** | ***4.8*** |

***Bold italic*** indicates estimates
[a] Percent of national electricity demand from wind = (wind generated electricity / national electricity demand) × 100
[b] [8]

and passed 5 GW mark in 2015. The installation rate is expected to continue and should reach 10 GW by 2020. In Germany, the offshore capacity was nearly tripled in 2015, reaching 3.3 GW at the end of the year. The new increased target of 7.7 GW in 2020 is expected to be reached in light of capacity under construction and projects awaiting final investment decisions. The Netherlands added 129 MW of offshore capacity in 2015 and had approximately 600 MW under construction. The target of 4,450 MW of offshore wind capacity in 2023 is expected to be reached with offshore tenders planned.

In Belgium delays in grid connection due to lack of social acceptance of land-based connections resulted in no added capacity in 2015. However, increases in offshore installations in 2016 and 2017 are expected to move towards the target of more than 2 GW in 2020. In Denmark, no offshore wind was installed in 2015. On the positive side, the results of the 400 MW Horns Rev 3 wind power plant tendering were published: 0.1031 EUR/kWh (0.1122 USD/kWh) over the next 11 to 12 years. In addition there are near-shore projects and 600 MW tendering in process.

France has tendered offshore wind power plants in 2012 (2 GW) and 2014 (1 GW) and is preparing a third round of offshore wind tenders. In 2015, a dedicated call for pilot projects of floating wind power plants was announced in France. After a lengthy planning phase, the first fixed-bottom projects are expected to start building phase in 2016–2017. In the United States, the first commercial offshore project (30 MW) is expected to come online in 2016 and 12 projects (3.3 GW) are expected by 2020. Japan installed one semi-offshore and one floating turbine in 2015. In Korea, starting construction of the 2.5-GW offshore demonstration wind plant is delayed. The 60-MW first phase is now planned for 2018.

In Finland, Ireland, and Sweden, no special subsidy schemes for offshore projects are in place because cost-effective land-based wind power still has good potential. A 40-MW demonstration plant is under construction in Finland. In Italy, shallow offshore sites are close to the shore where conflicts with visual impact of tourism areas have led to decreasing interest in offshore wind.

**Table 8. Offshore Wind Power Capacity in IEA Wind Member Countries 2011–2015**

| Country | 2011 Capacity (MW) | 2012 Capacity (MW) | 2013 Capacity (MW) | 2014 Capacity (MW) | 2015 Capacity (MW) |
|---|---|---|---|---|---|
| UK | 1,838 | 2,679 | 3,653 | 4,502 | 5,098 |
| Germany | 188 | 268 | 508 | 1,037 | 3,295 |
| Denmark | 871 | 920 | 1,271 | 1,271 | 1,271 |
| China | 263 | 390 | 428 | 658 | 1,015 |
| Belgium | 197 | 381 | 708 | 712 | 712 |
| Netherlands | 228 | 228 | 228 | 228 | 357 |
| Sweden | 163 | 163 | 211 | 211 | 211 |
| Japan | 25 | 25 | 50 | 50 | 53 |
| Finland | 26 | 26 | 26 | 27 | 27 |
| Ireland | 25 | 25 | 25 | 25 | 25 |
| Spain | 0 | 0 | 0 | 5 | 5 |
| Korea | 0 | 2 | 2 | 5 | 5 |
| Norway | 2 | 2 | 2 | 2 | 2 |
| Portugal | 2 | 2 | 2 | 2 | 2 |
| **Total** | **3,828** | **5,111** | **7,509** | **8,735** | **12,078** |

A large share of national and co-operative R&D efforts is spent on getting the costs down and developing new innovations offshore (Section 4 and Table 15). Research on floating offshore is funded in the countries with limited shallow waters, with the first pilots running.

### 2.3 National policies

Similar to the support many governments provide for a wide variety of energy sectors, all IEA Wind member countries have government or market structures designed to encourage wind energy development (Table 9). Feed-in tariffs (FIT) were used by 14 of the IEA Wind member countries to encourage wind development. Also popular with the IEA Wind member countries are programs that mandate utilities to supply a portion of electricity from renewables. Nine countries use these utility obligations, renewable obligations, or renewable portfolio standards.

Several countries are in the process of changing their wind energy policies. In order to better integrate large amounts of variable renewables in the electricity markets and system, the EU has changed the guidelines for incentive systems in favor of production premiums on top of electricity market income, recommending technology neutral incentives. Auctions are commonly used for offshore wind power. Production premiums on top of electricity market sales are already used in Finland, the Netherlands, and Spain. Production premiums began in the UK in 2015. Technology neutral certificates are used in Sweden and Norway (common market). A new program was announced in 2015 in France. Finland, Germany, and Ireland are currently ending existing programs and preparing new ones.

Wind energy cost competitiveness can also be increased through emissions trading. The EU Emissions Trading System (EU ETS) cap on carbon dioxide ($CO_2$) emissions has so far not delivered prices high enough to encourage the move to renewables, including wind energy [5].

### 2.4 Issues affecting growth

At the end of 2015, close to 58 GW of new wind power plants were planned and/or under construction in the reporting IEA Wind member countries (Table 10). The actual increases in capacity for 2016 and beyond will depend on resolution of the issues affecting growth, reported by the IEA Wind countries. Many of these issues are being addressed through national policies, national research projects, and co-operative research projects of IEA Wind and other groups. Denmark published a report in 2015 summarizing its long-term experience and lessons learned in promoting wind and renewable energy deployment [6].

Meeting their self-defined 2020 wind targets is already close in Austria, Denmark, Germany, and Sweden. Reaching the targets has been reported as uncertain in Italy and Spain. Belgium, France, the Netherlands, and the UK are still quite far from 2020 targets; in these countries the large offshore deployment in progress may close the gap.

#### *Policy changes*

Sudden changes in legislation and retroactive changes are seen as the biggest threats to wind power investors in Europe. In Spain, wind power deployment has stopped due to policy changes; 2015 was the first year with no added capacity since the 1980's. In the UK, a change in strategy impacted land-based wind power development in 2015.

Providing longer-term incentive structures, with known tariffs (even decreasing ones) reduces the effects of policy uncertainty. Belgium reported decreased uncertainty after moving towards more clear tariff changes that reflect adequate rates of return for investments to ensure financing. In Italy, the FIT has been set to a much lower level with steep reduction rate. In Austria and Switzerland, the reduced funds available for incentives have limited the deployment rate. In Portugal, annual deployment has declined since 2012. In that year, the Portuguese government changed policy to only allow projects that can fit the existing grid capacity; wind capacity was approaching the targets set for 2020.

In some countries with significant annual additions to capacity (Finland, Ireland, and Italy) incentive schemes are ending and there are uncertainties regarding the future. Uncertainty after current targets for 2020 are met and regarding the new EU guidelines towards technology neutral auctions are seen in Germany and the UK. Low green certificate prices together with low electricity market prices impacted new wind power projects in Sweden.

In the United States, the Production Tax Credit has been one of the most impactful federal incentives for utility-scale development. The Production Tax Credit expired in January 2015 and was extended in December 2015. While uncertainty surrounding its extension might have negatively impacted industry planning during the year, the Production Tax Credit will be in effect through 2019 to provide a stable market environment for years to come.

# 1 Executive Summary

**Table 9. Government Approaches to Promote Wind Power in IEA Wind Member Countries for 2015 into 2016**

| Type of Program | Description | Countries Implementing |
|---|---|---|
| Carbon tax | A tax on carbon that encourages a move to renewables and provides investment dollars for renewable projects. | The EU ETS - international system for trading greenhouse gas emission allowances covers more than 11,000 power stations, industrial plants, and airlines in 31 European countries; Canada has carbon taxes in 3 provinces. |
| Feed-in tariff | An explicit monetary reward for wind-generated electricity that is paid (usually by the electricity utility) at a guaranteed rate per kilowatt-hour that is usually higher than the wholesale electricity rates. | Austria, Belgium, Canada (3 provinces), China, Denmark (auctions for offshore), France (auctions for offshore), Germany (adjustable), Greece, Ireland, Italy, Japan, Korea, Portugal, Switzerland, the United States (for several states)<br>**(15 countries)** |
| Renewable portfolio standards (RPS), renewables production obligation (RPO), or renewables obligation (RO) | Mandate that the electricity utility (often the electricity retailer) source a portion of its electricity supplies from renewable energies. | Belgium, Canada (6 provinces), China, Italy, Korea, México (under development), the UK, the United States **(8 countries)** |
| Green certificates | Approved power plants receive certificates for the amount (MWh) of electricity they generate from renewable sources. They sell electricity and certificates. The price of the certificates is determined in a separate market where demand is set by the obligation of consumers to buy a minimum percentage of their electricity from renewable sources. | Belgium, México (under development), the Netherlands, Norway, Sweden, the UK, the United States **(7 countries)** |
| Spatial planning activities | Areas of national interest that are officially considered for wind energy development. | Belgium, China, Denmark, Ireland, Korea, México, the Netherlands, Sweden, the UK, and the United States **(10 countries)** |
| Green electricity schemes | Green electricity based on renewable energy from the electric utility, which can be purchased by customers, usually at a premium price. | Denmark, Finland, Ireland, the Netherlands, Norway, Sweden, the UK, the United States **(8 countries)** |
| Net metering or net billing (for small wind power plants) | The system owner receives retail value for any excess electricity fed into the grid, as recorded by a bi-directional electricity meter and netted over the billing period. Electricity taken from the grid and electricity fed into the grid are tracked separately, and the electricity fed into the grid is valued at a given price. | Canada, Denmark, Italy, the Netherlands, Portugal, the UK, the United States **(7 countries)** |
| Tax incentives | Some or all expenses associated with wind installation that may be deducted from taxable income streams, investments (Belgium), or import tax (China). | Belgium, Canada, China, Ireland, Norway, the Netherlands, the United States **(7 countries)** |
| Special incentives for small wind | Reduced connection costs, conditional planning consent exemptions. Value-added tax (VAT) rebate for small farmers. Accelerated capital allowances for corporations. Can include microFIT. | Canada, Denmark, Italy, Portugal, the UK, the United States **(6 countries)** |
| Financing incentives | For example: Shares in investment funds offered. Schemes that focus on wealth creation and business success using wind energy as a vehicle to achieve these ends. Preferential home mortgage terms for houses, including wind systems; and preferential green loans for the installation of wind systems | Canada, Ireland, the Netherlands, the UK **(4 countries)** |
| Capital subsidies | Direct financial subsidies aimed at the up-front cost barrier, either for specific equipment or the total installed wind system cost.<br>In Spain, auction: A fixed investment incentive such that an auction is based on a Capex reference value and the winner will be subsidized with a fixed price per MW. | China, Korea, Spain (auction) **(3 countries)** |
| Feed-in premium/ Contract for Difference | Subsidy is the difference between a guaranteed price and the electricity market price—producers are in the electricity markets | Finland, Netherlands, the UK **(3 countries)** |

**Table 10. Potential Increases to Capacity Beyond 2015 in Reporting IEA Wind Member Countries**

| Country | Planning Approval[a] (MW) | Under Construction[b] (MW) | Total Planned and/or Under Construction (MW) |
|---|---:|---:|---:|
| Austria | 700 | 240 | 940 |
| Belgium | 1,303 | 250 | 1,643 |
| Canada | 1,100 | --- | 1,100 |
| Finland | 200 | 200 | 400 |
| Germany | --- | Offshore: 1,202 | Offshore: 2,067 |
| Ireland | 538 | --- | 538 |
| Netherlands | Offshore: 600<br>Land-based: 825 | Offshore:145<br>Land-based: 865 | 2,435 |
| Norway | 4,568 | --- | 4,568 |
| Spain | 1,500 | 0 | 1,500 |
| Sweden | 8,925 | 424 | 9,349 |
| Switzerland | 0 | 0 | 0 |
| UK | Offshore: 2,830<br>Land-based: 1,200 | 5,700 | 9,730 |
| United States | 4,900 | 9,400 | 14,300 |

--- = no data available
[a] Projects have been approved by all planning bodies.
[b] Physical work has begun on the projects.

***Costs***

Generally, the trend of reduced cost of wind power installations (especially at low wind sites) opens up more possibilities and enhances wind deployment. In Ireland, decreases in wind turbine prices together with low interest rates have left the industry with good economic underpinnings and there is a strong appetite to build out permitted projects. However, growing costs for project development and for electricity market imbalance costs are reported from Austria. In the Netherlands, reduction of the green funding opportunities is reported. In the United States, the high cost of offshore wind generation is driving efforts to improve the performance and reliability and reduce the costs of offshore wind systems.

***Shortage of sites on land***

The limited availability of good sites on land is the challenge in the Netherlands. A project to find more suitable sites was set up and local governments, utilities, and developers collaborated in this initiative. A shortage of onshore wind sites was cited in several countries as a reason to develop offshore wind projects: Belgium, Denmark, Germany, Japan, Korea, the Netherlands, and the UK.

Radars (military, aviation and weather/meteorology) and safety distances (roads, airports) create areas where wind power cannot be built. Work to mitigate these challenges has been addressed in Belgium, Finland, Germany, and the United States. Changes to very strict regulations regarding environmental protection and nature reserve areas have been made in Korea and the Netherlands to allow more wind development sites in these densely populated countries.

***Curtailments, transmission, and grid integration***

In many countries, the capacity of electrical grids is limiting a large growth of wind power. In Italy, grid connection bottlenecks have been mitigated but still some delays with grid connections and especially new transmission lines are reported. In Ireland, grid connection has been the determining factor for rate of deployment, but in 2015 a review concluded that there is enough contracted wind capacity to fulfil the 2020 targets and beyond. In the United States, lack of access to transmission and interregional transmission have impeded wind deployment growth in some areas.

In cases of inadequate grid capacity and critical events in balancing supply and demand, system operators sometimes shut down or *curtail* production from wind power plants. Unclear rules of curtailment or lack of compensation for curtailed energy may increase risks for wind power producers. In China, the wind curtailment rate was 15%, an increase from the 7% in 2014. Measures to further resolve this problem are being taken by the government, like setting policies to promote the reform of the electric power trading system and improving market-based trading mechanisms. In Italy, reinforcing the grid has mitigated most of the curtailments.

In Ireland, the small system size has required the system operator to limit the instantaneous share of wind power in the generation system. The result is increased curtailments, reaching 4.4% in 2015. Measures are being taken to allow for the targeted 3.5 GW of wind without much higher curtailments, but some of them are behind schedule for implementation. The system operator raised the limit on instantaneous wind power penetration from 50% to 55% in October 2015, resulting in a reduction in curtailment.

In Japan, grid capacity has been taken up by a rush to solar power. In Hokkaido and Tohoku, wind power plants have been asked to accept unlimited (formerly maximum 30 days) and unpaid curtailments. In Japan, interregional grid extension is critical to reducing curtailments. However, the necessary power system reform is progressing only gradually.

The imbalance costs of day-ahead electricity trade are substantial in Austria, due to non-optimal market operation. These imbalance costs are threatening the economic viability of wind power producers, especially those dropping out of the FIT system in near future. In Ireland, the new market rules may disadvantage small wind power plants. In the United States, a comprehensive study of the cycling impacts of high penetration of wind on current fossil-fuel power plants revealed that the cost is minor compared to the benefits of reduced use of fossil fuels. IEA Wind Task 25 on wind integration is addressing several of these issues.

***Permitting delays***

Delays due to permitting requirements have limited and impeded wind development in several countries (Belgium, Finland, France, Italy, and Switzerland). Especially long resolving times for appeals against building projects have been reported from Belgium, Ireland, and the UK. Simplification of administrative rules has been ongoing in 2015 in Belgium, Denmark, France, the Netherlands, and Switzerland. The Netherlands is changing the approach towards offshore tenders, where the Ministry of Economic Affairs is taking the lead in site investigations before the tenders, reducing the burden of developers and speeding up the building process.

***Environmental impacts***

Concerns about environmental impacts and regulations were also mentioned as issues affecting the permitting of new wind projects in Finland, Ireland, Japan, and the Netherlands. Research projects on environmental impacts are underway in most countries. The IEA Wind Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN) will leverage the findings of these projects in their public web site launched in 2015. In the United States, an in-depth study of wildlife distribution and movements along the Eastern Seaboard was published in 2015. U.S. work on bat impact minimization techniques including ultrasonic acoustic deterrents is continuing.

Positive environmental impacts are reported for offshore deployment in Belgium, increasing biodiversity on the support structures. Another positive effect of wind generation is displacing fossil fuel consumption by the power sector and the related economic and environmental costs. Some countries calculate the avoided $CO_2$ emissions (million tons/year) attributable to wind energy: the United States (131.7), Germany (60), Spain (24.3), Italy (10.9), Portugal (4.1), and Finland (1.6). These calculations are based on the national generation mix and usage patterns of each country reporting.

In 2015, Health Canada researchers began to publish detailed results from their epidemiological study on noise and health impacts of wind turbines. A summary of results was released in November 2014. The study concluded that there is no evidence of a causal relationship between exposure to wind turbine noise and self-reported medical illnesses and health conditions, although it did identify a relationship with annoyance.

***Social acceptance***

Social acceptance is becoming an issue in nearly every country that has wind development. More involvement of local communities in project planning and offering the opportunity to take part in the projects is one way of avoiding lengthy appeal times (Belgium, the Netherlands). The Netherlands has drawn a Code of Conduct to broaden the basis of public support. In 2015, WindEurope launched a web-based tool to help increase the local participation in planning and implementation of wind power projects (WISE power available at ewea.org). IEA Wind Task 28 Social Acceptance of Wind Energy Projects is addressing the process of wind project development.

## 3.0 Implementation

### 3.1 Economic impact

In addition to the many environmental benefits of wind energy such as $CO_2$ reduction and increased biodiversity, the wind sector creates opportunities on the economic and industrial level and creates employment. Besides building the wind parks, there is a need for building the grid infrastructure and grid connection. Table 11 shows estimated labor and economic turnover effects for 2015 in the reporting IEA Wind member countries.

**Table 11. Capacity in Relation to Estimated Jobs and Economic Impact 2015**

| Country | Capacity (MW) | Estimated Number of Jobs | Economic Impact (million USD[a]) |
|---|---|---|---|
| China | 144,901 | 502,400 | --- |
| United States | 73,992 | 88,000 | 14,700 |
| Germany | 44,946 | 150,000 | 12,630 |
| Spain | 22,988 | 16,753 | 2,885 |
| UK | 13,614 | 30,758 | 12,628 |
| Canada | 11,205 | --- | 2,169 |
| France | 10,308 | 10,000 | --- |
| Italy | 8,942 | 26,000 | 3,339 |
| Portugal | 5,033 | Direct: 3,251<br>Total: 23,152 | 1,348 |
| Netherlands | 3,376 | Direct[b]: 5,450<br>Total[b]: 7,950 | 3,330 |
| México | 3,073 | 1,300 | --- |
| Ireland | 2,455 | 3,400 | 380 |
| Austria | 2,409 | 5,500 | 577 |
| Belgium | 2,229 | 12,500 | --- |
| Finland | 1,005 | 5,000 | --- |
| Korea | 835 | 2,424 | 943 |
| Switzerland | 60 | --- | 38 |
| **Total** | **368,534** | | |

--- = no data available

[a] Applicable conversion rate USD to EUR: 0.919

[b] From a 2014 report

A key benefit cited in many countries is the number of workers employed in the wind energy sector. Employment in the wind sector increased in 2015 over 2014 in all main markets: China, North America, and Europe. In the United States, wind turbine technician was the fastest growing profession in 2015. The workforce increased by more than 10,000 in 2015 to reach 88,000 with 21,000 in the manufacturing sector. In China, wind jobs surged from 356,000 in 2013 to 502,400 in 2015. More than 70% of the jobs are in manufacturing. In China, it is estimated that about 15 jobs could be produced by each megawatt of wind installation. Among these jobs, 13–14 are in the manufacturing industry, and about 1.5 jobs are involved in installation and maintenance.

In contrast, decreased annual deployment in Spain due to changes in the incentive scheme resulted in the loss of half of its wind power employment in six years. In Italy, the growing employment due to wind development has changed to a decline due to domestic market decreases.

Several landmark analyses were performed in 2015 to estimate the economic benefit of meeting deployment targets. In the United States, the *Wind Vision* report quantified the benefits and economic impacts of current and potential future wind energy deployment levels, such as 600,000 wind-related jobs by 2050. The Chinese government estimated that by 2020, more than one million people will be working in the wind power industry. In Ireland, a macroeconomic analysis of onshore wind deployment was published in 2015, anticipating between 2,880 and 6,000 new jobs in 2020. In Belgium, the offshore deployment is estimated to create 20,000 person years of employment during the building and development phase and 800 permanent jobs during operation. In the Netherlands and the UK, reports were published in 2014 showing an increase especially in offshore related business and gross value added.

Export markets can grow even if domestic markets are not growing. All Spanish companies have entered export markets and the exports remained at the level of 2014 in 2015 (2 billion EUR; 2.2 billion USD). In Denmark, the export market grew by 17% in 2015 (7.2 billion EUR; 8.7 billion USD). Increasing exports have been reported from Austria (0.6 billion EUR in 2015).

In Canada, successful examples in Ontario and Québec highlight the benefits for local communities from wind power plants, in the form of local jobs, tax revenues, and lease payments. In the UK, a standard community benefit fund for new projects is 5,000 GBP/MW (6,774 EUR/MW; 7,375 USD/MW). In Scotland, the wind energy industry contributes 8.8 million GBP (11.9 million EUR; 13 million USD) yearly to local communities.

### 3.2 Industry status

Table 12 reports the total number of turbines operating in the IEA Wind countries and the average rated capacity of the new turbines installed in 2015. Many details are presented in the country chapters of this report, such as share of manufacturers of installed capacity and domestic turbine and component manufacturers. A few examples are included here.

***Manufacturers***

Financial reports from manufacturers in Europe show that they have generally improved their results. Non-European wind turbines are gaining increased shares in global market. New large turbines were erected in 2015: MHI Vestas first two 8-MW turbines and Siemens 7-MW prototype were erected in Denmark; MHI 7-MW turbine on floating platform in Japan; Senvion 6.2-MW prototype in Germany; and 6-MW 2B Energy prototype in the Netherlands.

Consolidation processes within the wind energy sector are ongoing and two new mergers were announced in 2015: German Nordex with Spanish Acciona and French Areva with Spanish Gamesa for offshore turbines (Adwen). In Japan, Mitsubishi Heavy Industries has shifted its manufacture of turbines to the joint venture MHI Vestas Offshore Wind. In Korea, Samsung and Hyundai Heavy Industries have closed their wind businesses and only Doosan Heavy Industry and Unison continue wind development. Japanese Toshiba made a business partnership with Unison.

In the United States, at the end of 2015, there were more than 500 wind-related manufacturing facilities across 43 states, producing everything from major components like blades, nacelles, and towers down to bearings, fasteners, and sensors. In France, the offshore tenders led Alstom (now GE) and Areva (now Adwen) to announce the installations of major industrial facilities.

Several companies in Italy, Spain, and the United States are developing small wind turbines.

***Ownership***

Wind projects are owned by utilities, co-operatives, independent power producers (IPPs), private companies (i.e., industries for self-supply), income funds, and communities. The trend towards non-utility entities investing in wind energy continues. In the United States, power purchase agreements were signed by signed by Google Energy, Procter & Gamble, and General Motors in 2015. In Europe, companies including Google, IKEA, LEGO, and Unilever are turning to wind energy.

**Table 12. Turbine Details 2015**

| Country | Total Number of Turbines Operating | Average Capacity of All Turbines (MW) | Average Capacity of New Turbines (MW) |
|---|---|---|---|
| Austria | 1,109 | 2.2 | 3.0 |
| Belgium | 880 | 2.5 | Land-based: 2.1 to 3.2 |
| Canada | 6,066 | 1.8 | 2 0 |
| China | 92,698 | 1.6 | 1.8 |
| Denmark[a] | 5,776 | 0.9 | 3.1 |
| Finland | 387 | 2.6 | 3.1 |
| France | 4,500 | 2.3 | --- |
| Germany | Land-based: 25,982<br>Offshore: 792<br>Total: 26,774 | 1.7 | Land-based: 2.7<br>Offshore: 4.1 |
| Ireland | 1,503 | 1.6 | 2.6 |
| Italy | 6,484 | 1.4 | 2.2 |
| Japan | 2,077 | 1.5 | 2.2 |
| Korea | 432 | 1.9 | 2.6 |
| México | 1,789 | 1.7 | --- |
| Netherlands | 2,174 | 1.6 | --- |
| Norway | 374 | 2.3 | 2.3 |
| Portugal | 2,590 | 1.9 | 2.0 |
| Spain | 20,266 | 1.1 | --- |
| Sweden | 3,233 | 1.9 | 3.3 |
| Switzerland | 34 | 1.8 | --- |
| UK | 6,666 | 2.0 | 1.6 |
| United States | 48,500 | 2.0 | 2.0 |

[a] Average excluding small turbines <25kW.

***Bold italic*** indicates estimates; --- = no data available

In Canada, 23 of the 36 new wind energy projects commissioned in 2015 included significant ownership stakes by First Nations (jurisdictions governed by native peoples), municipal corporations, and local farmers. In Austria, 20% of the existing capacity is owned by cooperatives, and 40% by private companies.

### 3.3 Operational details

Wind power plants are becoming more productive by several measures. One of these is *capacity factor*. The annual capacity factor is the amount of energy a generating plant produces over the year divided by the amount of energy that would have been produced if the plant had been running at full capacity during that same time interval. For wind turbines, capacity factor is dependent on the quality of the wind resource, the

**Table 13. Reported Average Capacity Factors 2011–2015 (%)[a]**

| Country | Capacity Factor 2011 (%) | Capacity Factor 2012 (%) | Capacity Factor 2013 (%) | Capacity Factor 2014 (%) | Capacity Factor 2015 (%) |
|---|---|---|---|---|---|
| Austria | --- | 30.0 | 24.0 | ***24.0*** | --- |
| Belgium | Land: 21.0<br>Offshore: 41.2 | Land: 21.9<br>Offshore: 25.6 | Land: 21.6<br>Offshore: 24.8 | Land: 22.4<br>Offshore: 35.8 | Land: 21.5<br>Offshore: 41.9 |
| Canada | 31.0 | 31.0 | 31.0 | ***31.0*** | ***31.0*** |
| China | --- | 22.4 | 23.7 | 21.6 | 19.7 |
| Denmark | 28.4 | 22.6 | 27.1 | 30.8 | 32.6 |
| Finland | 28.0 | 24.0 | 26.0 | 27.0 | 32.0 |
| France | 21.7 | 24.0 | 23.2 | ***22.6*** | 24.3 |
| Germany | 19.0 | --- | 18.5 | 18.7 | Land: 22.7<br>Offshore: 45.7 |
| Greece | --- | --- | 27.5 | ***27.5*** | --- |
| Ireland | 31.6 | 28.4 | 30.5 | 28.7 | 32.3 |
| Italy | 18.0 | --- | 21.0 | ***20.0*** | 19.2 |
| Japan | 19.0 | 19.9 | 17.0 | 22.0 | 21.0 |
| Korea | --- | --- | --- | 23.7 | --- |
| México | 30.0 | 30.0 | 30.0 | ***30.0*** | --- |
| Netherlands | --- | Land: 20.0<br>Offshore 39.5 | Land: 22.3<br>Offshore: 38.6 | Land: 22.0<br>Offshore: 37.5 | Land: 25.6<br>Offshore: 40.0 |
| Norway | 31.3 | 31.2 | 29.2 | 31.0 | 35.0 |
| Portugal | 26.0 | 28.0 | 29.0 | 28.0 | 27.0 |
| Spain | --- | 24.1 | 26.9 | 25.4 | 23.9 |
| Sweden | --- | 26.0 | 28.3 | ***26.7*** | 33.0 |
| Switzerland | 20.0 | <20.0 | 20.0 | 20.0 | <20.0 |
| UK | Land: 27.4<br>Offshore: 36.7 | Land: 27.4<br>Offshore: 36.7 | --- | Land: 26.4<br>Offshore: 37.0 | 34.0 |
| United States | 33.0 | 33.0 | 32.1 | 32.3 | 32.0 |

***Bold italic*** indicates estimates; --- = No data available

[a] The amount of energy the plant produces over the year divided by the amount of energy that would have been produced if the plant had been running at full capacity during that same time interval.

technical availability (reliability), and the size of the generator in comparison of the length of the rotor blades. Long blades improve the capacity factors especially at low wind sites. The capacity factor is reduced if the utility curtails production.

Most wind power plants operate at a capacity factor of 25–40%. Offshore wind turbines generally have higher capacity factors due to excellent winds. The IEA Wind member countries' estimated average annual capacity factors for 2015 are reported in Table 13.

The IEA Wind member countries report a trend of installing turbines that have taller towers, longer blades, and comparatively smaller generators. These trends result in larger capacity factors for the new turbines and allow for wind development in more areas, including those with forests or lower wind speeds, resulting in better performance. For example, in Finland the capacity factors have increased from 20–30% to 30–40% and the high towers of 120–140m as well as larger blades have opened the deployment of inland forested areas. In Denmark, the average capacity factor was 32.6% (average wind index 114%). The 1,271 MW of offshore wind farms alone counted for nearly 35% of the production (4.8 TWh) with an average capacity factor of 43.4%. In China, the average capacity factor decreased again by about 10% compared to previous year. Curtailment of wind energy is one reason for the lower yield.

The average capacity of newly installed individual turbines was more than 3 MW in Denmark, Finland, Germany, and Sweden (excluding the <25 kW turbines). In most countries the average turbine capacity was above 2 MW. The average power rating of new wind turbines in 2015 was higher compared to 2014 in most countries.

In the United States, the average project size was about 201 MW and the average turbine size was 2 MW. In Europe almost half of the capacity ordered was for projects >30 MW and small projects <10 MW represented around 10% of the total. In contrast to generally larger project size, especially offshore, a trend of declining project size was reported for land-based wind in the Italy and the UK. Small wind power plants are increasing in Denmark and Italy.

### 3.4 Wind energy costs

Table 14 shows reported *turbine* and *project* costs in 2015 currency. Figure 3 shows trends of *project* costs since 2003 as reported by IEA Wind member countries in those years. Please note that the historic cost numbers (2003–2014) have been adjusted to 2015 Euros. As shown in Figure 3, installed costs are rising in some countries and falling in others.

Germany reports declining investment costs for land-based 2–3 MW wind power plants of 2–11% with an average of 7% from 2012 to 2015. In Germany, the overall O&M costs recorded for 2015 were on the same level as in 2014 despite a growing fleet of turbines, indicating that the operation of wind turbines is becoming more efficient. The repair and maintenance costs represent 44% of the operational costs for the first ten years increasing to 55% of the costs in the last ten years.

The trend toward using turbines on taller towers with larger rotors for a given generator capacity is working towards generating more electricity for the same installed power. The cost of electricity from wind generation (levelized cost of energy [LCOE]) is declining more than the investment costs. IEA Wind Task 26 is addressing this key metric, by collecting data on system and project costs, assessing methodologies for projecting future wind technology costs, and surveying methods for determining the value of wind energy (Lantz et al. 2012). The individual country chapters include estimated costs of energy based on local conditions.

The trend of lower costs is seen in some of the auction results. In Quebec, the latest contracts have an average price of 0.063 CAD/kWh (0.045 EUR/kWh; 0.054 USD/kWh) for the energy. In China, under the current technology, without considering the cost of long-distance transmission, the cost of wind power is higher than that of coal-fired power by 0.20 Yuan/kWh (0.027 EUR/kWh; 0.032 USD/kWh). If resources and environmental benefits are taken into consideration, the cost of wind power was nearly equal to that of coal-fired power generation. However, the targets for wind power are aiming at cost reductions, to reach the coal power plant cost of energy level in 2020.

In the UK, a yearly report on offshore costs shows the trend towards the targeted LCOE of 100 GBP/MWh (136 EUR/MWh; 148 USD/MWh) in 2020.

**Table 14. Estimated Average Turbine Cost and Total Project Cost for 2015 in Reporting IEA Wind Countries**

| Country | Turbine Cost (EUR/kW[a]) | Total Installed Project Cost[b] (EUR/kW[a]) |
|---|---|---|
| Austria | --- | 1,850 |
| Belgium | 1,251 | 1,686 |
| China | 639 | 1,327 |
| Germany | --- | 1,246 |
| Ireland | 900 | 1,650 |
| Italy | --- | 1,500 |
| Japan | 1,660 | 2,280 |
| Norway | 900 | 1,200 |
| Portugal | 1,308 | 1,635 |
| Spain | 935 | 1,320 |
| United States | 965 | 1,553 |

--- = No data available

[a] Applicable conversion rate 2015 EUR to 2015 USD: 1.088

[b] Total Installed Project Cost includes: costs for turbines, roads, electrical equipment, installation, development, and grid connection.

## 4.0 Research, Development, and Deployment (R, D&D) Activities

A significant benefit to countries that join the IEA Wind TCP is that relevant organizations within the country can participate in the co-operative research tasks. In 2015, there were 15 active research tasks sponsored by IEA Wind to advance wind energy technology and deployment. To guide these activities, the Executive Committee of IEA Wind has prepared a *Strategic Plan 2014–2019*, based on the document *Long-Term Research and Development Needs for Wind Energy for the Time Frame 2012 to 2030*. Figure 4 lists the active task activities and their time frames.

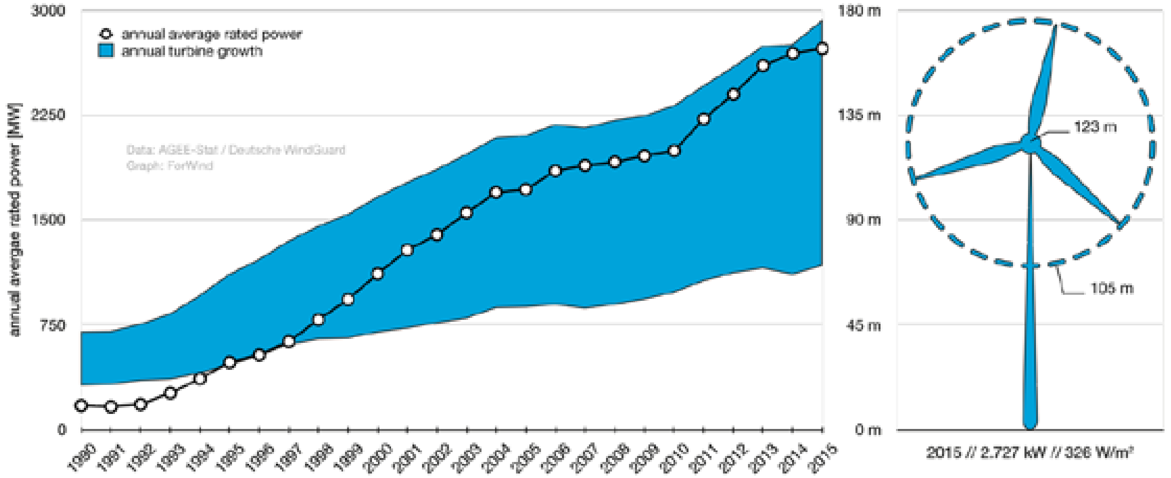

Figure 2. Trend for increasing turbine size, from Germany land-based capacity. (Source Deutsche Windguard. Download from www.windguard.com/service/knowledge-center/wind-energy-statistics/year-2015.html)

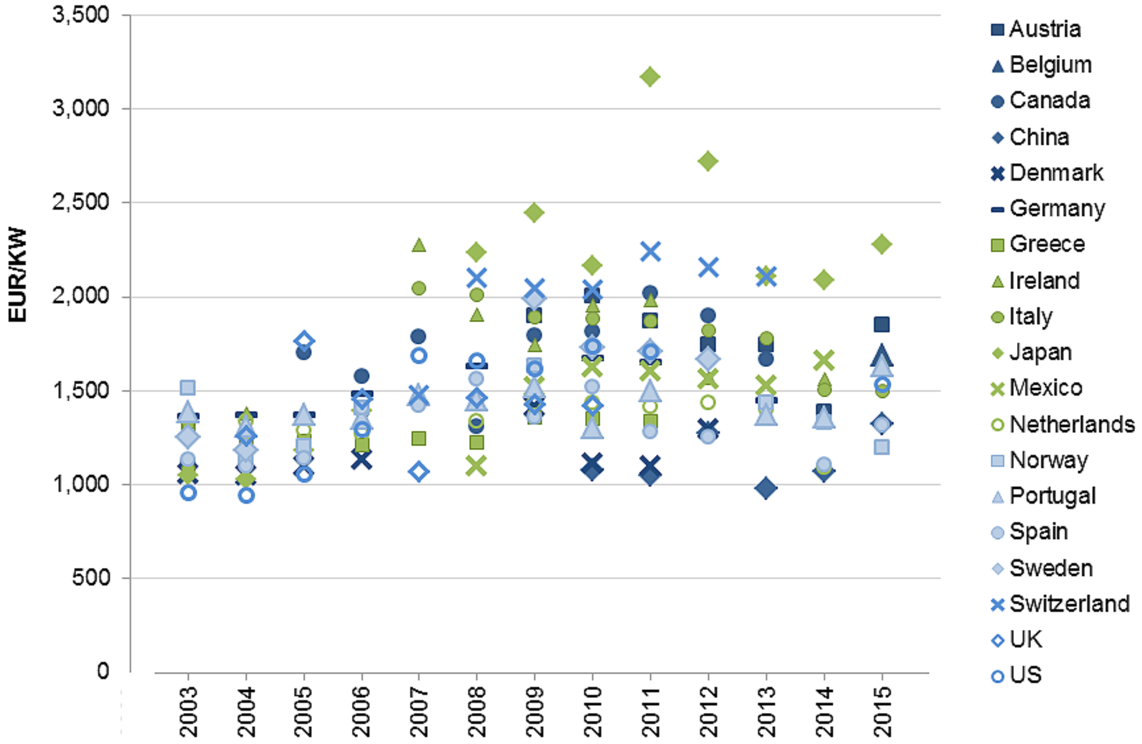

Figure 3. Average project cost of wind turbines on land 2003–2015 as reported by IEA Wind member countries. Prior-year costs were adjusted to 2015 values using Harmonised Inflation Europe (HICP) table averages by year. (www.inflation.eu/inflation-rates/europe/historic-inflation/hicp-inflation-europe.aspx)

### 4.1 National R&D efforts

The major research areas discussed in the individual country chapters are listed in Table 15. The country chapters contain references to recent reports and databases resulting from this research. A high priority on research to support offshore wind technology is continuing (China, Denmark, Finland, Germany, Italy, Japan, Korea, the Netherlands, Norway, Portugal, Spain, Sweden, the UK, and the United States, as well as the European Commission). More funding towards deep water floating technologies is also mentioned (France, Japan, Italy, Norway, Portugal, Spain, the United States, and the European Commission).

Government research support contributes to advancing wind technology and deployment. It is difficult to calculate the total research dollars supporting wind energy technology in many countries. However, Table 16 lists government budgets for wind R&D reported by some countries. Investments from research partners in industry and academia also contribute to advancing wind energy deployment.

National R&D topics are increasingly directed by the business sector, research centers, and universities, rather than by political and governmental organizations: Megavind in Denmark, ETIP Wind Industry Platform in the European Commission, Forschungsnetzwerk Erneuerbare Energien in Germany, TKI Wind Offshore in the Netherlands, ALINNE in Spain and The Offshore Wind Accelerator in the UK). These technology platforms and large research programs strive to have the R&D community work more in line with requests from the industrial sector; while the industrial sector is encouraged to make more use of the knowledge available in the research centers and universities.

#### 4.1.1 New test, research, and demonstration facilities

Important new test and demonstration facilities are listed below. The country chapters include more detail about on-going work with test, research, and demonstration facilities. Task 35 Full-Size Ground Testing of Wind Turbines and their Components is working on testing methods for nacelles and blades.

In France, the SEMREV test site became operational to test floating wind turbines off the coast at Le Croisic, on the Atlantic Ocean. In Germany, the Dynamic Nacelle Testing Laboratory (DyNaLab) in Bremerhaven was officially inaugurated. Also lightning strikes, short-circuit faults, and storm gusts can be simulated.

In the UK, the Crown Estate awarded lease agreements to three offshore wind demonstration sites in 2015: Gunfleet Sands extension (two new turbines), Blyth Offshore Wind demonstration site (100-MW, up to 20 offshore wind turbines and infrastructure) and European Offshore Wind Deployment Centre, Aberdeen Bay (up to 11 next-generation offshore wind turbines and other technologies).

In the United States, two state-of-the-art wind turbine drivetrain test facilities opened for business: the Clemson University Wind Turbine Drivetrain Testing Facility in South Carolina and a National Renewable Energy Laboratory (NREL) dynamometer at the National Wind Technology Center in Colorado. A new buoy equipped with meteorological/oceanographic instruments was deployed off the coast of New Jersey (AXYS WindSentinel) to complement a buoy deployed off the coast of Virginia in 2014.

#### 4.1.2 Highlights of research

Details of these and other completed projects, references to the resulting publications and descriptions of planned R&D activities can be found in the country chapters of this report.

**Table 15. Reported Research Activities in IEA Wind and Member Organizations**

| Topic | Country Activities Reported | IEA Wind Co-operative Activities |
|---|---|---|
| Offshore wind | • Technology development and turbine testing Foundations (fixed and floating)<br>• Installation<br>• Access<br>• Transmission issues<br>• Reliability of operation and maintenance<br>• Resource assessment | Task 30 Offshore Code Comparison Collaboration, Continued, with Correlation (OC5)<br>Task 11 Base Technology Information Exchange: Topical Expert Meeting |
| Small and medium-sized wind | • Technology development and turbine testing<br>• Tools for siting in urban settings<br>• Operation and maintenance costs reduction<br>• Noise reduction<br>• Assessing economics and usability<br>• Off-grid applications | Task 27 Small Wind Turbines at Turbulent Sites |
| Turbine technology improvement | • Blade materials and segmented manufacturing, longer blades, and low noise blades<br>• Taller towers<br>• Control systems<br>• Drivetrains: bearings, hydraulic transmission<br>• Optimizing performance<br>• Two-bladed, downwind turbines | Task 29 Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models<br>Task 35 Full-Size Ground Testing of Wind Turbines and Components<br>Task 37 Wind Energy Systems Engineering: Integrated R,D&D<br>Task 11 Base Technology Information Exchange: Topical Expert Meeting on noise reduction technologies and wind energy systems engineering |
| Innovative concepts | • Vertical axis turbines<br>• Hydraulic drives, superconducting drives<br>• Kites | |
| Operations and maintenance | • Condition monitoring<br>• Failure causes<br>• Service life estimation | Task 33: Reliability Data: Standardizing Data Collection for Wind Turbine Reliability and Maintenance Analyses |
| Cold and icing climates, severe conditions, and complex terrain | • Assessing the effects of icing on production<br>• Mitigating ice formation<br>• Assessing risks of ice fall<br>• Design for lightning, turbulence, and typhoons | Task 19 Wind Energy in Cold Climates<br>Task 11 Base Technology Information Exchange: Topical Expert Meeting |
| Resource assessment and forecasting | • Measurement programs and model development<br>• Mapping the wind resource – wind atlas<br>• Remote sensing techniques<br>• Forecasting techniques and implementation | Task 31 WAKEBENCH: Benchmarking of Wind Farm Flow Models<br>Task 36 Forecasting wind energy<br>Task 11 Base Technology Information Exchange: Topical Expert Meeting on uncertainty quantification of wind farm flow models |
| Integration with electric power systems | • Model and measure impacts of wind generation on the power supply system<br>• Using storage options and demand flexibility to mitigate system impacts<br>• System services from wind power plants<br>• Electricity market design | Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power |
| Environmental issues | • Developing impact assessment procedures<br>• Conducting assessments in sensitive areas<br>• Monitoring procedures<br>• Wildlife impact: birds, bats, aquatic species<br>• Sound propagation<br>• Impact on radar systems | Task 34 Working Together to Resolve Environmental Effects of Wind Energy<br>Task 11 Base Technology Information Exchange: Topical Expert Meeting on mitigation of wind turbine impacts on radar |
| Social acceptance | • Developing techniques for assessment and mitigation of negative attitudes toward wind projects to improve permitting and approval processes<br>• Measuring health impacts of wind | Task 28 Social Acceptance of Wind Energy Projects |

In Austria, the “Observation of Ice-falling-events Project” is generating a database of ice events in flat, semi-alpine, and alpine locations. The “Urban Small Wind Power Project” addresses the challenges of installation and operation of small wind turbines in urban, highly-turbulent areas.

In Belgium, researchers investigated the technical capability of wind farms to regulate their power infeed in real-time to balance the active power in the grid. The Enercon turbines in the study contributed to the delivery of secondary control power to the Belgian grid for a period of about two months. In the FONDEOLE project a new structure to anchor offshore wind turbines was developed, that decreased the amount of steel required for deep foundations.

In Canada, TechnoCenter Eolien (TCE) has developed digital image analysis tools that enable the characterization of icing events,

# 1 Executive Summary

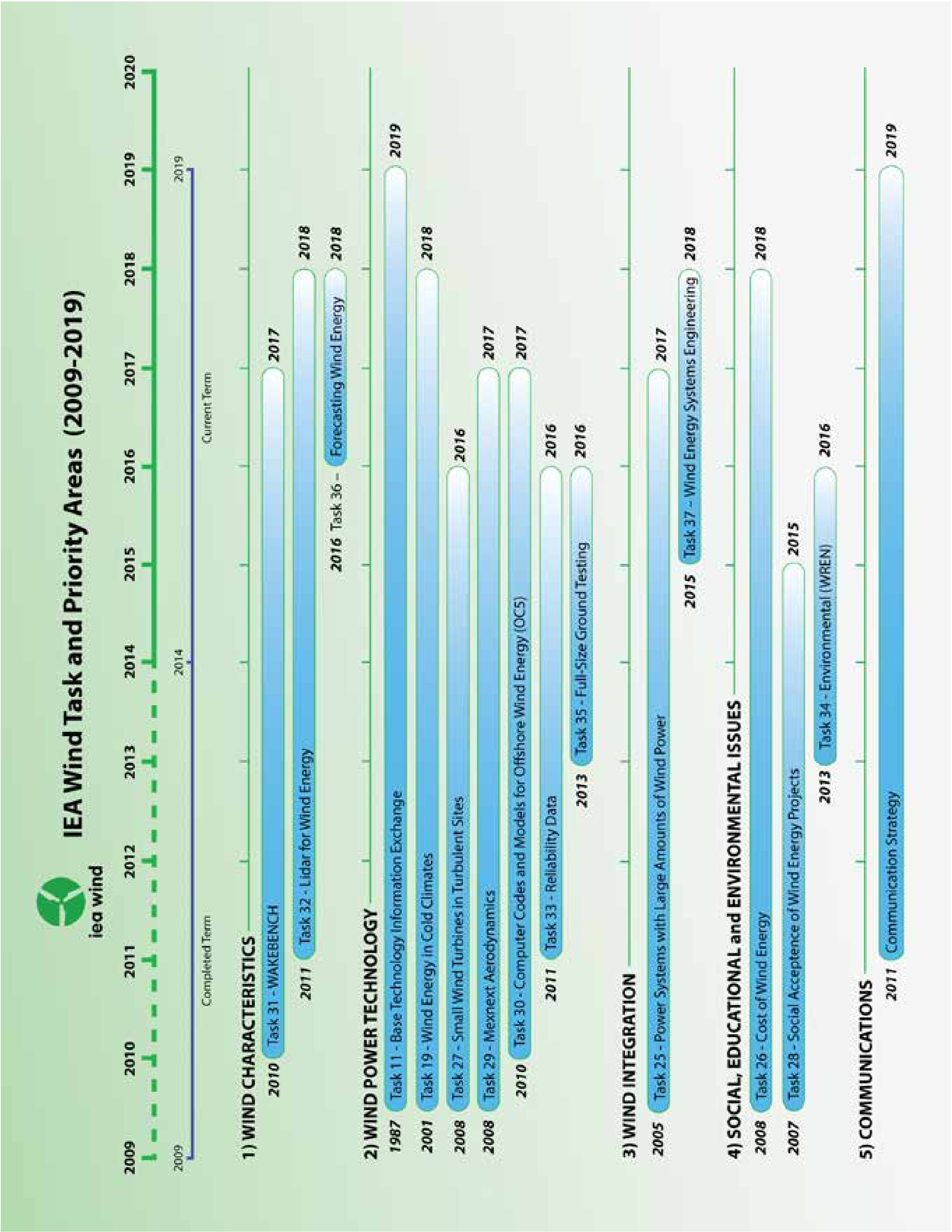

Figure 4. Priority areas from IEA Wind Strategic Plan and active research tasks [6]

**Table 16. National R&D Budgets 2012–2015 for Reporting Countries**

| Country | 2012ª Budget million EUR; (million USD) | 2013ª Budget million EUR; (million USD) | 2014 Budget million EUR; (million USD) | 2015 Budget million EUR; (million USD) |
|---|---|---|---|---|
| Belgium | 2.80;<br>(3.04) | 2.38;<br>(2.60) | 4.01;<br>(4.46) | 4.36;<br>(4.74) |
| Canada | 4.23;<br>(5.84) | 3.62;<br>(4.99) | ***3.89;<br>(4.71)*** | 2.15;<br>(2.34) |
| China | --- | --- | --- | 10.75;<br>(11.7) |
| Denmarkᵇ | 17.13;<br>(22.6) | 41.89;<br>(57.70) | --- | --- |
| European Commission | 61.35;<br>(80.94) | 65.67;<br>(90.46) | 24.71;<br>(29.92) | 91.9; (100)<br>+ demonstration<br>197.6; (215) |
| Finland | 2.00;<br>(2.75) | 3.12;<br>(4.30) | 0.99;<br>(1.20) | 1.7<br>(1.85) |
| Germany | 78.31;<br>(103.21) | 36.75;<br>(50.64) | 38.51;<br>(46.64) | 91.10;<br>(99.12) |
| Ireland | 0.88;<br>(1.07) | --- | --- | --- |
| Italy | 3.00;<br>(3.89) | 3.00;<br>(4.13) | ***3.00;<br>(3.63)*** | 2.48;<br>(2.7) |
| Japan | 41.89;<br>(55.26) | 25.05;<br>(47.50) | 52.73;<br>(63.84) | 117.15;<br>(127.46) |
| Korea | 33.91;<br>(44.69) | 35.60;<br>(49.06) | --- | --- |
| México | --- | --- | 1.74;<br>(2.10) | --- |
| Netherlands | 8.10;<br>(11.60) | 5.07;<br>(7.00) | 3.73;<br>(4.51) | --- |
| Norway | 17.14;<br>(22.68) | 13.20;<br>(18.19) | 12.39;<br>(15.00) | 9.38;<br>(10.2) |
| Spain | 120.00;<br>(158.16) | 85.50;<br>(117.82) | --- | 86.40;<br>(94.00) |
| Sweden | 10.80;<br>(14.23) | 10.80;<br>(14.88) | 6.45;<br>(7.81) | 7.08;<br>(7.70) |
| Switzerland | 0.41;<br>(0.53) | 0.41;<br>(0.53) | 0.39;<br>(0.47) | 0.51;<br>(0.55) |
| United States | 70.90;<br>(93.50) | 49.51;<br>(68.20) | 43.12;<br>(52.2) | 98.3;<br>(107) |

***Bold italic*** indicates estimates; --- = no data available
ª Currency is expressed in year of budget. It is not adjusted to present value.
ᵇ Projects supported by public funds

of ice itself, and the impact of both on electricity production. Senvion is partnering with TCE to carry out a project to optimize the production of their wind turbines in icing conditions. Several wind farms across Canada are implementing Generating Availability Data System (GADS) reporting, which allows comparison across the wind industry and with traditional electricity generators. The Wind Energy Institute of Canada (WEICan) is processing the data and providing statistics to data contributors of the project.

In Denmark, the Megavind partnership published a report *Danish Knowledge Institutions and their Contribution to a Competitive Wind Industry*.

In France, three floating wind projects are currently on-going: the Twinfloat concept using contra-rotative vertical axis turbines; a semi-submersible concept with Haliade 6-MW turbine, and a concrete barge using the Damping Pool concept with a prototype installed in 2015.

In Germany, the “HAPT – Highly Accelerated Pitch Bearing Test” project is increasing the reliability of rotor blade bearings and facilitates the application of new bearing-related technologies in wind turbines with a power of up to 10 MW. This is achieved through calculation models as well as test strategies. The “BiSWind” project implements a new measurement and maintenance principle with an autonomously operating Condition Monitoring System that is independent of external energy sources.

In Italy, KiteGen research has set up a 3-MW kite wind generator in southern Piemonte for testing.

In the Netherlands the C-Tower project demonstrates the feasibility of replacing a steel tower with a fiber-reinforced composite structure. This approach should reduce maintenance and thereby the life cycle cost of the entire wind turbine. It should also reduce production costs by using automated production techniques.

In Spain, researchers began the demonstration and certification of an offshore technology foundation with self-erecting telescopic tower.

In the UK, the Offshore Renewable Energy Catapult acquired the Levenmouth 7-MW demonstration offshore wind turbine, from Samsung Heavy Industries (SHI). This is the world's most advanced open access offshore wind turbine dedicated to research and product validation. In addition, the secure database of offshore wind farm performance data SPARTA (System Performance, Availability and Reliability Trend Analysis) was launched.

In the United States, the Department of Energy published three offshore wind reports in 2015: the *Offshore Wind Jobs and Economic Development Impacts in the United States: Four Regional Scenarios*; the *2014–2015 U.S. Offshore Wind Technologies Market Report*; and the *Offshore Wind Projects* report. The Wind Career Map released in 2015 shows the broad range of careers and skillsets across the wind industry and highlights paths of advancement among jobs within wind energy sectors. Another study identified multiple pathways to achieving a 30% share of wind and solar in the U.S. Eastern Interconnection—one of the largest power systems in the world. Newly released wind resource maps show the land areas with capacity factors over 35% at turbine hub heights of 110 and 140 meters.

### 4.2 Collaborative research

The collaborative research conducted by organizations in the IEA Wind member countries made significant progress in 2015. New tasks on forecasting and systems engineering started in 2015. Any of the ongoing tasks may be extended beyond the endpoint in Figure 4 if the participants agree and the Executive Committee approves the work plan. New tasks are added as the member countries agree on new research topics for co-operation.

Highlights of the work in Tasks in 2015 are described here. For details on recent activities and published reports, refer to the Task chapters in this report. Task web pages can be found at www.ieawind.org.

Task 11 Base Technology Information Exchange held three Topical Expert Meetings in 2015: Wind energy systems engineering; Uncertainty quantification of wind farm flow models; and Mitigation of wind turbine impacts on radar. Proceedings from these meetings of invited experts will be posted on the IEA Wind website. For 2016, two Topical Expert Meetings are scheduled: Aerodynamics and Offshore Wind Financing Risks. Two addition topics are under consideration: Downwind Turbines and Smart Structures for Large Wind Turbine Rotor Blades.

Task 11 also works together with other Tasks for IEA Wind Recommended Practices that serve as pre-normative guidelines in advance of formal standards. In 2015, new or updated Recommended Practices were under development in Task 19 Wind Energy in Cold Climates, Task 31 WAKEBENCH: Benchmarking Wind Farm Flow Models; Task 32 Wind LIDAR Systems for Wind Energy Deployment; and Task 33 Reliability Data: Standardizing Wind Data Collection for Wind Turbine Reliability and O&M Analyses.

Task 19 Wind Energy in Cold Climates participants wrote the *Available Technologies* report (published spring 2016). Update of the IEA Wind *Recommended Practices 13: Wind Energy Projects in Cold Climates*, aimed at wind farm developers and financiers, is anticipated for 2016. Task 19 is providing necessary pre-standards for the cold climate wind community, focusing on ice throw risk mitigation guidelines, and validation of the IEA Wind Ice Classification. Free, open-source software T19IceLossMethod is available on the Task 19 website. It is a standardized method for evaluating production losses due to icing, using only supervisory control and data acquisition (SCADA) data.

Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power participants uploaded a Wind Generation Time Series to their website. It is an Excel sheet with year 2012 hourly data from 12 European countries and Quebec. Short summaries of wind integration issues were published as fact sheets for general audiences. Collaborative journal articles on the following topics were published in 2015: Estimating $CO_2$ impacts of wind power; Variability in large-scale wind power generation; Wind integration impacts in hydro dominated systems; Capacity value of wind; Wind curtailments; and Power system stability issues.

Task 26 Cost of Wind Energy participants surveyed top experts in the field about their perspectives on future cost of energy for land-based, fixed-bottom offshore, and floating offshore wind systems – this work will be published in 2016. This is the first large-scale global expert survey on future wind energy costs and related technology advancements. With over 160 experts participating, it is the largest known ever performed on an energy technology in terms of expert participation.

Task 27 Small Wind Turbines at Turbulent Sites published several journal articles on topics of roof-top wind power design standards, monitoring campaigns and wind potential assessments, turbulence and structural loading.

Task 28 Social Acceptance of Wind Energy Projects has worked on its final report to be published in 2016, including topics of "positive intermediary" and "monitoring and assessment." Task 28 will apply for a continuing phase in 2016.

Task 29 Mexnext III Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models started a new phase in 2015. The work has shown progress in comparing load calculations with the measurements. It has also used high fidelity models, which require limited CPU-time in comparison to full computational fluid dynamic analyses.

Task 30 Offshore Code Comparison Collaboration Continued, with Correlation (OC5) published the final report on OC4 in 2015. Participants are currently running a complete set of load cases for the floating semi-submersible structure, and will validate the simulated results against measurements from tank testing of the system. Preparations for the runs and validations with Alpha Ventus demonstration data are being made.

Task 31 Wakebench: Verification, Validation, and Uncertainty Quantification of Wind Farm Flow Models published *Model Evaluation Protocol for Wind Farm Flow Models*, 1st edition in 2015. Current wind energy models often lead to over-prediction of wind plant performance leading to high uncertainties. The Task is working towards developing a verification, validation, and uncertainty quantification framework.

Task 32 LIDAR: Wind Lidar Systems for Wind Energy Deployment will start a second phase in 2016 to identify and mitigate barriers to the use of lidar for following wind energy applications: site assessment, power performance, loads and control, and complex flow detection. The Task will update the current recommended practice document from 2013, *Ground-Based Vertically-Profiling Remote Sensing For Wind Resource Assessment*. Participants will also issue an IEA Wind Recommended Practice on floating lidar systems in 2016, based on the work done in Phase 1.

Task 33 Reliability Data: Standardization of Data Collection for Wind Turbine Reliability and Operation & Maintenance Analyses is collecting and summarizing the competencies gained as an IEA Wind Recommended Practice for reliability data. This will be published in 2016 and disseminated in an industry workshop planned as a side event to the WindEurope (formerly EWEA) Wind Energy Conference in Hamburg, Germany.

Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN) launched the WREN Hub in 2015. This website has been populated with documents and information pertaining to environmental issues of both land-based and offshore wind energy. It currently hosts more than 2,600 papers and reports, of which more than 2,100 are pertinent to wind and wildlife. In addition to the public website, WREN webinars and white papers are used to disseminate the growing knowledge on environmental effects of wind energy development.

Task 35 Full-Size Ground Testing of Wind Turbines and their Components is working in two subtasks addressing blade and nacelle testing. The blade test group published framework documents in 2015 and the nacelle subtask is currently specifying the load cases for robustness tests and controller optimization.

Tasks 36 Forecasting for Wind Energy and Task 37 Wind Energy Systems Engineering: Integrated Research, Design, and Development started in late 2015 and will produce the first results in 2016.

## 5.0 The Next Term

Wind energy production will continue to supply an increasing percentage of the electricity needs of the world. Increasing performance of the world's wind generation fleet will continue to expand its role in the electricity generation portfolio. Wind turbines with towers, blades, and generators designed for specific locations will incorporate the latest technology to extract the greatest amount of energy from the wind. On land, improved technology will allow expanded, cost-effective installation of wind turbines in forested and otherwise complex terrain. Offshore wind applications will greatly expand the generation capacity of many nations. The technology is progressing towards cost reductions and with portfolios of projects under construction and more tenders announced, the yearly market growth is anticipated to continue. Wind energy will continue to attract new investors in both consolidated and new markets.

Work to reduce and remove barriers to deployment is continuing. With wind energy reaching larger shares of the electric generation supply, public acceptance and grid integration are receiving more attention. The 2020 targets set in Europe are approaching with some countries already close to meeting their targets, while others have made good progress. In some countries, consistent market mechanisms supporting wind energy will be needed to restart growth in deployment. To ensure long-term investments, industry is awaiting clear energy policy signals supporting wind energy after 2020.

**References and notes:**

Opening photo: Wind farm in France (Photo credit: Maia Eolis)

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Statistics for IEA Wind member countries have been provided by the authors of the country chapters and represent the best estimates of their sources in March 2016. For the latest information, visit www.ieawind.org.

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# 2 Activities of the IEA Wind Technology Collaboration Programme (TCP)

## 1.0 Introduction

**The overall aim of IEA Wind is to support development of cost-effective wind turbine systems that can be connected to an optimized and efficient grid or be used to supply electricity without being connected to the grid. National governments and international organizations agree to participate in the IEA Wind Technology Collaboration Programme (TCP) (formerly referred to as the IEA Wind Implementing Agreement). By joining, their researchers, utilities, companies, universities, and government departments may benefit from the active research tasks and information exchange of the group. Interested parties in Member Countries or Sponsor members (international organizations) should contact their executive committee representative (Appendix B) about ways to benefit from the IEA Wind research tasks. The most current Contact List of IEA Wind Members can be found at www.ieawind.org.**

**Under the auspices of the International Energy Agency (IEA*), the Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems (IEA Wind†) is a collaborative venture among 26 contracting parties from 21 Member Countries, the Chinese Wind Energy Association (CWEA), the European Commission, and WindEurope (formerly the European Wind Energy Association) (Table 1). Since it began in 1977, participants have worked together to develop and deploy wind energy technology through vigorous national programs and through co-operative international efforts. They exchange the latest information on their continuing and planned activities and participate in selected IEA Wind research tasks.**

**Each year, the IEA Wind TCP issues a report on its activities and those of its Member Countries and organizations. This, the thirty-eighth IEA Wind Annual Report, lists accomplishments by the close of 2015. The Executive Summary (Chapter 1) compiles information from all countries and tasks to highlight important statistics and trends. Activities completed in 2015 and planned for 2016 are reported for the overall collaboration (Chapter 2) and for the research tasks (Chapters 3 through 17). Member Country chapters (Chapters 18 through 40) describe activities in the research, development, and deployment of wind energy in their countries during the year just ended. The IEA Wind 2015 Annual Report is published by PWT Communications, LLC in Boulder, Colorado, United States, on behalf of the IEA Wind Executive Committee (ExCo).**

## 2.0 Collaborative Research

Participation in research tasks (Table 2) is open to any organization located in member countries of IEA Wind (Table 1). Member countries choose to participate in tasks that are most relevant to their current national research and development programs. A lead organization in each country must agree to the obligations of task participation (agree to perform specified parts of the work plan and pay a common fee for management of the task). Research tasks are approved by the ExCo as numbered annexes to the Implementing Agreement text. Tasks are referred to by their annex number. The numbers of active tasks are not sequential because some tasks are extended and some have been completed and do not appear as active projects.

In 2015, 15 active tasks were exploring issues of wind energy research, development, and deployment (R, D&D). New research tasks: Task 36 on forecasting and Task 37 on Systems Engineering were approved in 2015. Additional tasks are planned when new areas for co-operative research are identified by members.

The combined effort devoted to a task is typically the equivalent of several people working full-time for a period of three years. Each participant has access to research results many times greater than could be accomplished in any one country. Some tasks have been extended so that work can continue. Some projects are cost-shared and carried out in a lead country. Other projects are task-shared, in which the participants contribute in-kind effort, usually in their home organizations, to a joint research program coordinated by an operating agent (OA). In most projects, each participating organization agrees to carry out a discrete portion of the work plan. Often a participation fee from participating countries supports the work of the OA to coordinate the work and handle reporting to the ExCo.

**Table 1. Contracting Parties to IEA Wind TCP in 2015**

| Country/Organization | Contracting Party to TCP |
|---|---|
| Austria | The Republic of Austria |
| Belgium | Government of Belgium |
| Canada | Natural Resources Canada |
| CWEA (Sponsor) | Chinese Wind Energy Association |
| Denmark | Danish Energy Authority |
| European Commission | The Commission of the European Communities |
| Finland | The Finnish Funding Agency for Technology and Information (TEKES) |
| France | Government of France |
| Germany | Federal Ministry for Economic Affairs and Energy (BMWi) |
| Greece | Center of Renewable Energy Resources (CRES) |
| Ireland | Sustainable Energy Authority of Ireland (SEAI) |
| Italy | 1) Ricerca sul Sistema Energetico (RSE S.p.A.)<br>2) Italian National Agency for New Technology, Energy and Sustainable Economic Development (ENEA) |
| Japan | National Institute of Advanced Industrial Science and Technology (AIST) |
| Korea | Government of Korea |
| México | Instituto de Investigaciones Electricas (IIE) |
| Netherlands | The Netherlands Enterprise Agency |
| Norway | 1) The Norwegian Water Resources and Energy Directorate (NVE)<br>2) Research Council of Norway |
| Portugal | National Laboratory of Energy and Geology (LNEG) |
| Spain | Energetica Medioambiental y Tecnologica (CIEMAT) |
| Sweden | Swedish Energy Agency |
| Switzerland | Swiss Federal Office of Energy |
| United Kingdom | Offshore Renewable Energy Catapult |
| United States | U.S. Department of Energy |
| WindEurope (Sponsor) | WindEurope (formerly European Wind Energy Association) |

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* The IEA was founded in 1974 within the framework of the Organization for Economic Co-operation and Development (OECD) to collaborate on international energy programs and carry out a comprehensive program about energy among member countries. The 29 OECD member countries, non-member countries, and international organizations may participate. For more information, visit www.iea.org.

† The IEA Wind implementing agreement (also known as the Wind Energy Technology Collaboration Programme [TCP]) functions within a framework created by the International Energy Agency (IEA). Views and findings in this Annual Report do not necessarily represent the views or policies of the IEA Secretariat or of its individual member countries.

# 2 IEA Wind TCP

**Table 2. Active Cooperative Research Tasks (OA indicates operating agent that manages the task)**

| | |
|---|---|
| Task 11 | Base Technology Information Exchange<br>OA: Vattenfall, Sweden (1987–2008) changed to CENER, Spain (2009–2012; 2013–2014; 2015–2016) |
| Task 19 | Wind Energy In Cold Climates<br>OA: Technical Research Centre of Finland (VTT), Finland (2001–2011; 2012–2015; 2016–2018) |
| Task 25 | Design and Operation of Power Systems with Large Amounts of Wind Power<br>OA: Technical Research Centre of Finland – VTT, Finland (2005–2011; 2012–2014; 2015–2017) |
| Task 26 | Cost of Wind Energy<br>OA: National Renewable Energy Laboratory (NREL), United States (2008–2011; 2013–2015; 2015–2018) |
| Task 27 | Small Wind Turbines in High Turbulence Sites<br>OA: CIEMAT, Spain (2012–2016) |
| Task 28 | Social Acceptance of Wind Energy Projects<br>OA: ENCO Energie-Consulting AG, Switzerland (2007–2011; 2012–2015) |
| Task 29 | Mexnext: Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models<br>OA: ECN, the Netherlands (2012-2014; 2015–2017) |
| Task 30 | OC3/OC4/OC5: Offshore Code Comparison Collaborative Continuation with Correlation<br>OA: NREL, the United States and Fraunhofer Institute for Wind Energy and Energy System Technology (IWES), Germany (2010–2013; 2014–2017) |
| Task 31 | WAKEBENCH: Benchmarking of Wind Farm Flow Models<br>OA: CENER, Spain, and NREL, United States (2011–2014; 2015–2017) |
| Task 32 | LIDAR: Wind Lidar Systems for Wind Energy Deployment<br>OA: ForWind Centre for Wind Energy Research, Germany (2012–2015); Stuttgart Wind Energy (SWE), University of Stuttgart, Germany (2016–2018) |
| Task 33 | Reliability Data: Standardising Data Collection for Wind Turbine Reliability and Operation and Maintenance Analyses<br>OA: Fraunhofer IWES, Germany (2012–2016) |
| Task 34 | Working Together to Resolve Environmental Effects of Wind Energy (WREN)<br>OA: NREL, United States (2013–2016) |
| Task 35 | Full-Size, Ground Testing of Wind Turbines and Components<br>OA: Rheinisch Westfälische Technische Hochschule (RWTH) Aachen University, Germany (2013–2016) |
| Task 36 | Forecasting for Wind Energy<br>OA: DTU Wind Energy, Risø, Denmark (2015–2018) |
| Task 37 | Wind Energy Systems Engineering: Integrated Research, Design, and Development<br>OA: NREL, United States (2015–2018) |

By the close of 2015, 20 IEA Wind research tasks had been successfully completed, two tasks had been deferred indefinitely, and 15 were working on solving issues of wind energy technology and deployment. The work in 2015 and plans of the active tasks are described in Chapters 3–17 of this IEA Wind Annual Report. For more information about the ongoing co-operative research activities, contact the OA representative for each task listed in Appendix B of this report). Table 3 shows participation by members in active research tasks in 2015.

Final reports, technical reports, plans, and Recommended Practices produced by tasks are available through the IEA Wind website: www.ieawind.org.

## 3.0 Executive Committee (ExCo)

The ExCo consists of a member and one or more alternate members designated by each participating government, contracting party, or international organization that has signed the IEA Wind Implementing Agreement. Most countries are represented by one contracting party that is a government department or agency. Some countries have more than one contracting party in the country. The contracting party may designate members or alternate members from other organizations in the country. International organizations may join IEA Wind as sponsor members.

The ExCo meets twice each year to exchange information on the R, R&D programs of the members, to discuss work progress on the research tasks, and to plan future activities. Decisions are reached by majority vote or, when financial matters are decided, by unanimity. Members share the cost of administration for the ExCo through annual contributions to the Common Fund. The Common Fund supports the efforts of the Secretariat and other expenditures approved by the ExCo in the annual budget, such as preparation of this Annual Report and maintenance of the ieawind.org website.

**Table 3. Member Participation in Research Tasks During 2015**

| Participant* | Research Task Number | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 11 | 19 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Austria | | x | | | x | | | | | | | | | | |
| Belgium | | x | | | | | | | | | | | | | |
| Canada | | x | x | | | | | | | x | | | | | |
| CWEA | x | x | x | | x | | x | x | | x | x | | x | | |
| Denmark | x | x | x | x | x | x | x | x | x | x | x | | x | OA | x |
| European Commission | | | | x | | | | | | | | | | | |
| Finland | x | OA | OA | | | | | | x | | x | | | x | |
| France | | | x | | | | x | x | x | x | x | x | | x | |
| Germany | x | x | x | x | | x | x | x | x | OA | OA | x | OA | x | x |
| Greece | x | | | | | | | | | | | | | | |
| Ireland | x | | x | x | x | x | | | | | x | x | | x | |
| Italy | x | | x | | | x | | x | | | | | | | |
| Japan | x | | x | | x | x | x | x | x | x | | | | | |
| Korea | | | | | x | | | x | | | | | | | |
| Mexico | x | | x | | | | | | | | | | | | |
| Netherlands | x | | x | x | | | OA | x | x | x | x | x | | | x |
| Norway | x | | x | x | | | x | x | | x | x | x | | x | x |
| Portugal | | | x | | | | | x | | | | | | x | |
| Spain | OA | | x | | OA | | | x | OA | | | x | | x | x |
| Sweden | x | x | x | | | | x | | x | | x | x | | x | |
| Switzerland | x | x | | | | OA | | | x | | | x | | | |
| UK | x | | x | x | | | | | | x | x | x | x | x | x |
| United States | x | | x | OA | x | x | x | OA | x | x | x | OA | x | x | OA |
| WindEurope | | | x | | | | | | | | | | | | |
| Totals | 16 | 9 | 18 | 8 | 8 | 7 | 9 | 12 | 10 | 10 | 11 | 10 | 5 | 11 | 7 |

*For the latest participation data, check the task websites at www.ieawind.org
**OA indicates Operating Agent that manages the task

***Officers***

In 2015, Jim Ahlgrimm (United States) served as chair; Ignacio Marti (United Kingdom), John McCann (Ireland), and Brian Smith (United States) served as Vice Chairs. Ignacio Marti (United Kingdom was elected as chair beginning in 2016. Stephan Barth (Germany) was elected as a vice chair beginning in 2016 and the other vice chairs were re-elected to serve in 2016.

***Participants***

In 2015, there were several personnel changes among the members and alternate members representing their organizations (See Appendix B: IEA Wind Executive Committee 2015). For the latest and most complete ExCo member contact information, please click the IEA Wind Members tab at www.ieawind.org.

Belgium was accepted as a new participating country during 2015.

***Meetings***

The ExCo met twice in 2015 to review ongoing tasks, approve publications, plan for new tasks, and report on national wind energy research, development, and deployment activities (R, D&D). The first meeting of the year was devoted to reports on deployment activities in Member Countries and in the research tasks. The second meeting was devoted to reports from Member Countries and tasks about R&D activities.

The 75th ExCo meeting was hosted by the Swiss Federal Office of Energy. The meeting was held in Neuchâtel, Switzerland, 5–7 May

2015. Thirty-seven participants included ExCo members or alternates from 18 participating countries and sponsor members and an observer from the IEA Secretariat. Presentations were given about all 13 active research tasks. The Common Fund audit report for 2014 was approved. The hosts sponsored a technical tour of the Mont Crosin wind and PV park and EPFL lab (wind tunnel) at Saint Imier and Lausanne.

The 76th ExCo meeting was hosted by the Government of France at IFP Energies nouvelles. The meeting was held in Rueil-Malmaison outside of Paris, France. The 39 participants included ExCo Members or Alternates from 18 participating countries and sponsors; observers from the IEA Secretariat, Ireland, and the Republic of Korea also participated. The ExCo welcomed Belgium as the newest member of IEA Wind. The Government of Belgium designated the Department of Energy to carry out the responsibilities. The Common Fund budget for 2016 was approved. The hosts sponsored a demonstration on lidar measurements and use of lidars by LeoSphere (a French lidar supplier) and a session with a presentation from Georgina Grenon on French national policies, followed by three technical presentations of French projects on floating wind.

## 4.0 Decisions, Publications, and Outreach

In 2015, IEA Wind approved proposals for two new tasks: Task 36 Forecasting for Wind Energy and Task 37 Wind Energy Systems Engineering: Integrated Research, Design, and Development

Approved publications in 2015 included:

- 8 fact sheets produced by Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power are designed to explain important technical aspects of wind power and grid integration for policymakers and ratepayers. One fact sheet covers overall Integration Issues. These issues are linked to fact sheets on Variability, Balancing, Capacity, Storage, Emissions, Stability, and Transmission.
- A report of Task 26 Cost of Wind Energy titled *IEA Wind Task 26 Wind Technology, Cost, and Performance Trends in Denmark, Germany, Ireland, Norway, the European Union, and the United States: 2007–2012*.
- The Task 29 Mexnext-II aerodynamics Final *Technical Report and Final Management Report*.
- The deliverables for Phase 1 of Task 31 WAKEBENCH: *Best Practice Guidelines for Wind Farm Flow Models and Model Evaluation Protocol.*
- A Task 32 LIDAR expert group report *Estimating Turbulence Statistics and Parameters from Ground- and Nacelle-Based Lidar Measurements.*
- Task 34 WREN (Working Together to Resolve Environmental Effects of Wind Energy) launched and web-based information hub for research on environmental impacts of wind energy on land and offshore

Recommended Practices are under development in several tasks.

The ExCo approved extending Task 19 Wind Energy in Cold Climates, Task 26 Cost of Wind Energy, Task 29 Mexnext-III improving aerodynamic models, Task 31 Wakebench: Benchmarking Wind Farm Flow Models, Task 32 LIDAR: Wind lidar systems for wind energy deployment. The ExCo approved a one-year extension of Task 33 Reliability Data: Standardizing Data Collection for Wind Turbine Reliability, Operation, and Maintenance Analyses.

The *IEA Wind 2014 Annual Report* was published in August 2015 and 1,200 copies were printed and distributed to member organizations. Press releases were issued with links to the electronic version on the website. The Executive Summary of the 2014 Annual Report was printed as a separate document (1,000) and shipped to members with the Annual Reports.

To showcase the accomplishments of the 15 IEA Wind cooperative research efforts, the planning committee organized a side event at the European Wind Energy Association 2015 Annual Conference. This side event was intended to give industry players and researchers insight into the latest results of IEA Wind research topics, and provide an overview of the broad range of collaborative research activities developed in the context of IEA Wind. The session consisted of four panels:

- Wind Technology Development
- Wind Characteristics and Integration
- Wind Turbine Testing and Certification
- Social, Environmental, and Economic Aspects of Wind Energy

**Table 4. Priority Areas Address Strategic Objectives**

| Priority Areas | Strategic Objectives | | | | Active Tasks |
|---|---|---|---|---|---|
| | Reduce cost of wind energy use | Increase flexibility of transmission and power systems | Increase social acceptance of wind energy projects | Increase exchange of best practices | Collaborative IEA Wind efforts to address priority area |
| 1: Wind Characteristics | • | | | • | 11, 19, 27, 31, 32, 36 |
| 2: Wind Power Technology | • | | • | • | 11, 19, 26, 27, 29, 30, 33, 35 |
| 3: Wind Integration | • | • | | • | 11, 25, 37 |
| 4: Social, Educational, and Environmental Issues | • | | • | • | 11, 26, 27, 28, 34 |
| 5: Communications | | | • | • | All |

The website, www.ieawind.org, continued to expand coverage of IEA Wind activities. Three Task 11 Proceedings of Experts Meetings were posted on the public website in 2015: Wind Energy Systems Engineering: Integrated RD&D, Floating Offshore Wind Plants, and Field Test Instrumentation and Measurement Best Practices. The 2014 Annual Report, Executive Summary, Task 25 fact sheets on integration, Task 26 technology cost and performance trends report, and the Task 34 WREN hub were announced through LinkedIn as part of the expanding social media outreach for the IEA Wind TCP. In addition, countless journal articles, conference presentations, and poster presentations drew upon the work of the IEA Wind research tasks. Many of these are posted on the task websites accessible from the home page of IEA Wind.

A planning committee consisting of the Chair, Vice Chairs, the Secretary, the former Chair, and the OA Representative for Task 11 Base Technology Information Exchange perform communication and outreach activities between ExCo meetings. One of these activities is providing support for IEA Paris initiatives. For example, an ExCo member attended the 68th IEA Renewable Energy Working Party meeting in Lausanne, Switzerland to deliver a 2-page report on IEA Wind activities.

Invitations to attend ExCo meetings were extended to Belgium, Israel, and IRENA. All countries with active interest in wind energy are welcome to explore participation by contacting the Chair or Secretary by email at ieawind@comcast.net.

## 5.0 Strategic Planning 2014–2019 and Long-Term R&D Needs through 2030

Conducting activities that are in line with the Strategic Plan were major goals of IEA Wind in 2015. The strategic plan set the goal of major cost reduction by conducting R&D in five strategic areas: 1) characterise the wind resource to support reliable and cost-optimised technology, 2) develop wind turbine technology for future applications such as large, highly reliable machines for offshore applications in shallow or deep waters, 3) develop technology that facilitates the integration of this variable energy source into energy systems, 4) improve existing methods to forecast electricity production from wind energy systems and to control wind power plants for optimal production and distribution of electricity, and 5) address challenges related to implementation uncertainties such as physical planning to optimise land use and minimise negative effects to people and nature. Table 4 outlines these priority areas, objectives, and active tasks directed at the priority areas.

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[1] See End-of-Term Report 2009–2013 and Strategic Plan 2014–2019. 2013. www.ieawind.org.

# 3 Task 11

## Base Technology Information Exchange

### 1.0 Introduction

**The objective of Task 11 of the IEA Wind Technology Collaboration Programme (TCP) is to promote and disseminate knowledge on emerging wind energy topics. This is accomplished through meetings of invited experts for information exchange on R&D topics of common interest to the IEA Wind members. Knowledge is also disseminated by Task 11 by developing IEA Wind Recommended Practices for wind turbine testing and evaluation. So far, 16 IEA Wind Recommended Practices have been issued. Many of the IEA Wind Recommended Practices documents have served as the basis for both international and national standards.**

**Nearly every country of the agreement participates in this important task. These cooperative activities have been part of IEA Wind since 1978. Task 11 is an important instrument of IEA Wind, which allows members to react quickly to new technical and scientific developments and information needs. Task 11 documents bring the latest knowledge to wind energy experts in the member countries and present collections of information and recommendations for the work of the IEA Wind TCP. Task 11 is also an important catalyst for starting new IEA Wind research tasks.**

**Following Task 11 meetings, resulting documents are made available to organizations in countries that participate in the Task. After one year, documents can be accessed on the IEA Wind public webpages (www.ieawind.org) under the Task 11 heading.**

**Table 1 lists the countries participating in Task 11 in 2015. These countries pay a fee to support the work of the Operating Agent that manages the Task. The Spanish National Centre of Renewable Energies (CENER) is the current Operating Agent.**

### 2.0 Objectives and Strategy

The objective of Task 11 is to promote wind turbine technology through information exchange among experts on research, technology, and innovation topics of common interest. This exchange is primarily achieved by holding Topical Expert Meetings (TEMs) of invited experts. The meetings are hosted by organizations from the countries participating in Task 11.

The goal is to hold four TEMs on different topics each year. Active researchers and experts from the participating countries are invited to attend these meetings. Meeting topics selected by the IEA Wind Executive Committee have covered the most important topics in wind energy for decades. A TEM can also begin the process of organizing new research tasks for the IEA Wind TCP. Table 2 lists the TEMs held in the last two years (2014–2015). A list of all TEMs and links to their reports can be found on the ieawind.org website under Task 11.

A second activity of Task 11 is to develop IEA Wind Recommended Practices for wind turbine testing and evaluation. IEA Wind has issued 16 IEA Wind Recommended Practices and many of these documents have served as the basis for both international and national standards (Table 3).

### 3.0 Progress in 2015

#### 3.1 Topical Expert Meetings

The TEM's are conducted as workshops, where information is presented and discussed in an open manner. The participants themselves decide what they want to present. Guidance for presentations is given in the Introductory Note that is distributed along with the invitation to the meeting.

Generally, the meetings last two days and oral presentations are expected from all participants. The agenda usually covers the following items:

1. Collection of proposals for presentations
2. Introduction by the host
3. Introduction by the Operating Agent, recognition of participants
4. Presentation of the Introductory Note
5. Individual presentations
6. Discussion
7. Summary of the meeting.

Three TEMs were held in 2015 and the proceedings of the conducted meetings are published on the FTP server for country members. They are available to the public one year after each meeting on www.ieawind.org.

##### 3.1.1 TEM #80: Wind energy systems engineering

The meeting on wind energy systems engineering: integrated R, D&D was held on 12–13 January 2015, hosted by NREL in Boulder, Colorado, United States. Nineteen presentations were given and 23 people participated from countries including Denmark, Germany, Korea, the Netherlands, Spain, the UK, and the United States.

**Table 1. Countries and Organizations Participating in Task 11 During 2015**

| | Country/Sponsor | Organization(s) |
|---|---|---|
| 1 | CWEA | Chinese Wind Energy Association (CWEA) |
| 2 | Denmark | Danish Technical University (DTU) |
| 3 | Finland | Technical Research Centre of Finland (VTT) |
| 4 | Germany | Center for Wind Energy Research (ForWind) |
| 5 | Greece | Center of Renewable Energy Resources (CRES) |
| 6 | Ireland | Sustainable Energy Agency Ireland (SEAI) |
| 7 | Italy | Ricerca sul Sistema Energetico (RSE S.p.A.) |
| 8 | Japan | National Institute of Advanced Industrial Science and Technology (AIST) |
| 9 | México | Instituto de Investigaciones Electricas (IIE) |
| 10 | Netherlands | Rijksdienst Voor Ondernemend (RVO) |
| 11 | Norway | Norwegian Water Resources and Energy Directorate (NVE) |
| 12 | Spain | Centro de Investigaciones Energéticas, Medioambientales, y Tecnológicas (CIEMAT) |
| 13 | Sweden | Energimyndigheten (Swedish Energy Agency) |
| 14 | Switzerland | Swiss Federal Office of Energy (SFOE) |
| 15 | UK | Offshore Renewable Energy Catapult (ORE) |
| 16 | United States | U.S Department of Energy (DOE) |

# 3 Task 11

**Table 2. Topical Experts Meetings (2014–2015)**

| No. | Meeting Title | Year |
|---|---|---|
| 83 | Mitigation of Wind Turbine Impacts on Radar | 2015 |
| 82 | Uncertainty Quantification of Wind Farm Flow Models | 2015 |
| 81 | Noise Reduction Technologies (cancelled) | 2015 |
| 80 | Wind Energy Systems Engineering | 2015 |
| 79 | Meso-Scale to Micro-Scale Model Coupling (cancelled) | 2014 |
| 78 | Field Test Instrumentation and Measurement Best Practices | 2014 |
| 77 | Best Practices for Wind Turbine and Plant End of Life (cancelled) | 2014 |
| 76 | Floating Offshore Wind Plants | 2014 |

The primary goal was to advance methods in multi-disciplinary design, analysis, and optimization (MDAO), and to clarify the need for benchmarking efforts in MDAO at different levels of the system, wind turbine, and wind farm. Four groups were formed to discuss the main aspects of system engineering in wind turbines and wind plants. Topics selected for the discussion were:

- Advanced methods in multi-disciplinary design, analysis, and optimization
- Frameworks for integrated R, D&D of wind plants
- Reference turbines
- Reference plants

The participants decided that more development of these methods would be useful and therefore a specific IEA Wind research task covering the selected priorities could be launched.

### 3.1.2 TEM #81: Noise reduction technologies

At IEA Wind Executive Committee meeting 73 in Newcastle, UK it was decided to arrange a TEM on noise reduction technologies. The meeting was scheduled to be held in Glasgow, Scotland on 23–24 April 2015, hosted by Ore Catapult (UK) and was jointly organized in coordination with a biennial conference on wind turbine noise scheduled for 20–23 April 2015. However, the minimum number of registered experts was not met so the meeting was cancelled.

### 3.1.3 TEM #82: Uncertainty quantification of wind farm flow models

The TEM on uncertainty quantification of wind farm flow models was hosted by the Wind Energy Campus at the Uppsala University in Gotland, 12 June 2015 in Visby, Sweden. Ten presentations were given at the meeting that was attended by 19 participants from countries including China, Denmark, Japan, Spain, Sweden, and the United States. This meeting on uncertainty quantification of wind farm flow models responded to growing interest in the topic expressed at various wind energy forums.

IEA Wind has several research tasks related to model evaluation at various sub-system levels. For external wind conditions it is active under Task 31 WAKEBENCH: Benchmarking Wind Farm Flow Models. This task has developed methodologies for model verification and validation. Participants have conducted a series of model inter-comparison benchmarking exercises to compare models against each other and against observational data. This TEM was organized together with the kick-off meeting of the second phase of Task 31 WAKEBENCH in order to map the knowledge that the wind energy sector currently has on uncertainty quantification (UQ) applied to wind farm flow models.

The primary goals of this TEM were:

- Gather experts on UQ working in the wind energy field
- Identify state-of-the-art UQ techniques that can be reasonably applied to wind farm flow models in engineering practice
- Discuss potential challenges in the implementation of UQ methods
- Outline a work plan for IEA Wind Task 31 to develop a UQ framework

While the TEM was focused on wind farm flow models, the meeting was open to experts on uncertainty quantification in general.

### 3.1.4 TEM #83: Mitigation of wind turbine impacts on radar

This meeting was held in the Fraunhofer-Institut für Hochfrequenzphysik und Radartechnik FHR in Wachtberg, Germany, 6–7 October 2015. Three IEA Wind TEMs on the topic radar, radio links, and wind turbines were organized in the past:

- TEM #60 November 2009 (SenterNovem, Netherlands)
- TEM #53 March 2007 (Oxford, UK)
- TEM #45 March 2005 (London, UK)

At the previous IEA Wind TEMs on this subject the effects of wind turbines on radar and radio systems were presented from the perspective of wind farm and radar system operators. Mitigating techniques and ways to work around the policy issues have been discussed.

The objective of this 2015 TEM was to exchange information from experts who are working with mechanisms, tools, or equipment that can help mitigate the problem wind turbines cause for radars. Topics for discussion included:

- Radar friendly wind turbine blades
- Lower radar cross section
- New/modified/infill radars
- Radar processing improvements
- Wind turbine-radar test activities

This TEM helped participants understand ways to mitigate the effect of wind turbines on radars. It offered potential mechanisms to mitigate this barrier to wind turbine deployment in areas near long range air defense, air traffic control, and weather radars. Eleven expert participants from countries including Germany, Ireland, the Netherlands, Norway, Sweden, and the United States presented on the effects of wind turbines on radars and solutions to mitigate this effects.

**Table 3. IEA Wind Recommended Practices**

| No. | Area | Edition | Year | First Ed. | Valid | Status |
|---|---|---|---|---|---|---|
| 16 | Wind Integration Studies | 1 | 2013 | | Yes | |
| 15 | Remote Sensing for Wind Resource Assessment | 1 | 2013 | | Yes | |
| 14 | Social Acceptance of Wind Energy Projects | 1 | 2013 | | Yes | |
| 13 | Wind Energy Projects in Cold Climates | 1 | 2012 | | Yes | |
| 12 | Consumer Label for Small Wind Turbines | 1 | 2011 | | Yes | |
| 11 | Wind Speed Measurement and use of Cup Anemometers | 2 | 1999 | | | Document will be used by IEC 61400 MT 13, updating power performance measurement standards |
| 10 | Noise Emission Measurement | 1 | 1997 | | Yes | |
| 9 | Lightning Protection | 1 | 1997 | | Yes | See also IEC TR61400-24, Lightning protection for wind turbines |
| 8 | Glossary of Terms | 2 | 1993 | 1987 | | See also IEC 60050-415 International Electrotechnical vocabulary: Wind turbine generator systems |
| 7 | Quality of Power | 1 | 1984 | | | Superseded by IEC 614000-21, Measurement and assessment of power quality of grid connected wind turbines |
| 6 | Structural Safety | 1 | 1988 | | No | See also IEC 614000-1, ed. 2 |
| 5 | Electromagnetic Interference | 1 | 1986 | | Yes | Also see CENELEC Draft prEN50373, Wind Turbines - Electromagnetic compatibility |
| 4 | Measurement of Noise Emission | 3 | 1994 | | No | Superseded by IEC 61400-11, Acoustic noise measurement techniques |
| 3 | Fatigue Load Characteristics | 2 | 1990 | 1984 | Yes | Part of IEC 61400-13 TS, Measurement of mechanical loads |
| 2 | Estimation of Cost of Energy from WECS | 2 | 1994 | 1983 | Yes | |
| 1 | Power Performance Testing | 2 | 1990 | 1982 | | Superseded by IEC 61400-12, Wind Power Performance |

### 3.2 Future meetings

Planned TEMs for 2016 are:

- TEM #84: Aerodynamics, 13 January 2016, NREL, Boulder, Colorado, the United States
- TEM #85: Offshore Wind Financing Risks, 18 May 2016, Utrecht, the Netherlands

Two additional topics are under consideration: Downwind Turbines and Smart Structures for Large Wind Turbine Rotor Blades.

## 4.0 Plans for 2016 and Beyond

In addition to organizing and conducting the TEMs planned for 2016 and conducting a Joint Action Symposium on aerodynamics, the Operating Agent of Task 11 will work with the Operating Agents of following tasks to develop additional IEA Wind recommended practices:

- Task 30 Offshore Code Collaboration Comparison, Continued with Correlation (OC5)
- Task 31 WAKEBENCH: Benchmarking of Wind Farm Flow Models
- Task 32 Wind LIDAR: Lidar Systems for Wind Energy Deployment
- Task 33 Reliability Data: Standardizing Data Collection for Wind Turbine Reliability, Operation, and Maintenance Analysis
- Task 35 Full-Size, Ground Testing for Wind Turbines and Their Components
- Task 37 Wind Energy Systems Engineering: Integrated Research, Design, and Development

**References:**

Opening photo: U.S. National Renewable Energy Laboratory's test wind facility, host of TEM #84 on aerodynamics (Photo credit: Xabier Munduate)

Author: Xabier Munduate, National Renewable Energy Center (CENER), Spain.

# 4 Task 19

## Wind Energy in Cold Climates

### 1.0 Introduction

**Deployment of wind energy in cold climate areas is growing rapidly because of favorable wind conditions, increased air density leading to higher energy yields, low population densities (fewer social impacts), and increasing technological solutions. Wind resources in cold climate areas are typically good, but icing of turbines and low ambient temperatures pose additional challenges for wind energy projects. Icing of wind turbine rotor blades reduces energy yield and the mechanical lifetime of turbines, and it increases noise emissions as well as safety risks due to risk of ice throw. Low temperatures can affect turbines' mechanical lifetime if they are not taken into account in turbine design by using appropriate materials.**

**Cold climate areas have gained more focus compared to the earlier years as the wind energy deployment targets have been updated. Also, increased experience, knowledge, and improvements in cold climate technologies have enabled the economics of wind projects to become competitive in relation to standard wind projects.**

**By the beginning of 2013, the wind capacity in cold climates in Asia, Europe, North America, and Scandinavia was approximately 70 GW although only a small portion of this wind turbine fleet was designed for icing and low-temperature conditions. The potential for installing new capacity between 2013 and 2017 in cold climate areas, such as in Canada, China, the northern United States, and northern Scandinavia, is vast, totaling 50 GW and representing 20% of total global capacity.**

**Icing challenges are also observed in more moderate, warmer climate areas in high altitude locations in France, Portugal, Spain, and Central and Eastern European countries. This means that the stimulus for further development of wind power projects and technology in cold climates is strong.**

**Turbine manufacturers have developed technical solutions for low temperatures for their standard turbines. First- and second-generation commercial solutions for de- and anti-icing of wind turbine blades have entered in the markets. R&D activities have been conducted in a number of countries to master the difficulties that atmospheric icing and low temperatures create. These activities aim to improve the economics of wind power in new areas around the globe. The coming years will be important for validating the new information and for analyzing the performance of the adapted technologies arising from on-going wind energy projects, as well as making more information publically available.**

**In the absence of large international R&D funding programs (e.g., in EU Horizon 2020 for cold climate) and sporadic nature of national cold climate research activities, an expert group under the IEA Wind TCP, has been working to solve the additional challenges of cold climates since 2002. The participants in IEA Wind Task 19 Wind Energy in Cold Climates collect, evaluate, and create information covering all aspects of wind energy in cold climates. For example, they are assessing sites in icing conditions, clarifying the economics of cold climate wind projects, and improving health and safety issues and procedures. Table 1 shows the countries and organizations participating in Task 19 during 2015.**

### 2.0 Objectives and Strategy

The objectives of IEA Wind Task 19 for 2015 were as follows:

- Review current standards and recommendations from the cold climate point of view and identify possible needs for updates.
- Validate the IEA Wind Ice Classification used for estimating the effects of atmospheric icing on energy production.
- Determine the current state of cold climate solutions for wind turbines, especially anti-icing and de-icing solutions that are available or are entering the market.
- Clarify the significance of extra loading that ice and cold climate induce on wind turbine components.
- Create a new Task 19 Available Technologies report and update the expert group study on guidelines for applying wind energy in cold climates.

The items above have been identified as key topics that are slowing cold-climate wind power development. The ongoing national R&D activities in task-participant countries are contributing to tackling these challenges and sharing new information and expertise on the subject.

The results of the ongoing national activities will improve the overall economy of wind energy projects in cold climates and, thus, significantly lower the risks of development in areas where low temperatures and atmospheric icing occur. The collaboration actively disseminates results through conferences and seminars, as well as the IEA Wind Task 19 website (www. ieawind.org/task_19.html).

©VTT 2010 (Photo by A. Vignaroli)

### 3.0 Progress in 2015

In 2015, the main activities of Task 19 focused on major updates to the upcoming reports. A 2013 report, *IEA Wind Task 19 State-of-the-Art of Wind Energy in Cold Climates* will be updated and renamed *Available Technologies for Wind Energy in Cold Climates*. The Available Technologies report will target engineering and scientific audiences. In contrast, another previous key report, *Recommended Practices 13: Wind Energy Projects in Cold Climates* is aimed at wind farm developers and financiers. A full draft of the Available Technologies report has been written and the report will be published later in 2016.

In 2015, for the updated Recommended Practices, three major focus points were prioritized in order to provide necessary pre-standards for the cold climate wind community:

1. Ice throw risk mitigation guidelines
2. Free, open-source software: T19IceLossMethod, a standardized method for evaluating production losses due to icing, using only supervisory control and data acquisition (SCADA) data
3. Validation of the IEA Wind Ice Classification

**Table 1. Countries and Organizations Participating in Task 19 During 2015**

| | Country/ Sponsor | Organization(s) |
|---|---|---|
| 1 | Austria | Energiewerkstatt Verein |
| 2 | Belgium | SIRRIS OWI-LAB |
| 3 | Canada | TechnoCentre éolien |
| 4 | CWEA | China Aerodynamic Research and Development Center (CARDC) |
| 5 | Denmark | DTU Wind Energy |
| 6 | Finland | VTT Technical Research Centre of Finland Ltd |
| 7 | Germany | Fraunhofer IWES |
| 8 | Sweden | WindREN<br>Meventus |
| 9 | Switzerland | Meteotest |

# 4 Task 19

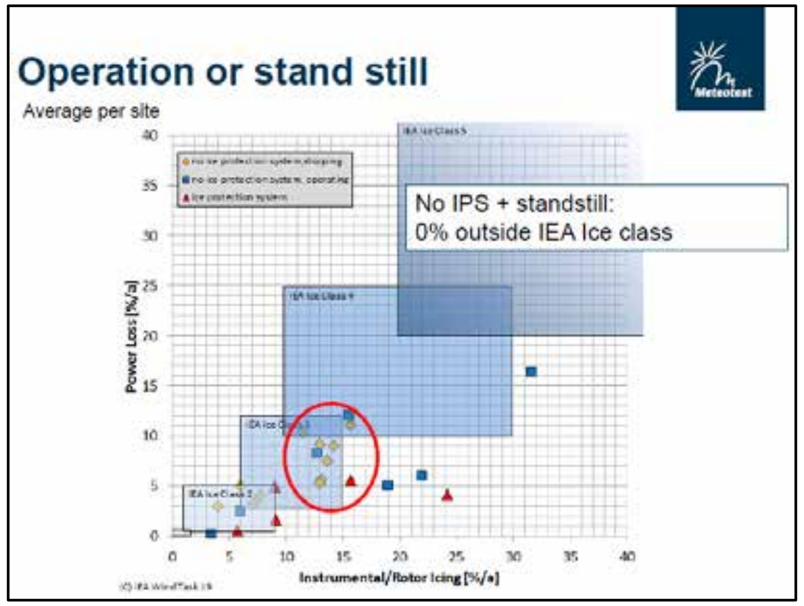

Figure 1. Validation of IEA Wind Ice Classification [1]

The T19IceLossMethod is freely downloadable from the IEA Wind Task 19 website and includes an updated version 1.1. The T19IceLossMethod will enable extensive validation of the widely-used IEA Wind Ice Classification table developed in 2012 and will boost dissemination of information among data owners (developers) and the scientific community. With the ice throw guidelines, new, safer wind farms can be planned using the step-by-step approach. The ice throw guidelines can also be used as a platform for standardizing vocabulary and applicable ice throw risk assessment methodologies. The IEA Wind Ice Classification validation results were presented at WinterWind 2016 (Figure 1) showing that the Ice Classification, in general, well represents the long-term average production losses due to icing for specific measured instrumental icing durations.

During 2015, members of Task 19 were invited as speakers and chairs in numerous seminars, conferences, and workshops dealing with cold-climate wind energy. In total, Task 19 made more than seven public presentations; executed two conference panel discussions that were highlighted in the conference programs; and published several white papers and journals articles. Numerous Task 19 references were mentioned, mainly in the following events:

**Table 2. Task 19 Activities for 2016–2018**

| | Topics | | | |
|---|---|---|---|---|
| | Deployment of wind energy in cold climates | Ice measurement, forecasting, and mapping | Toward certified practices for cold climate solutions | Safety and acceptance |
| Motives | Increase industrial awareness and interest | Better tools for site condition and energy yield assessment | Bring cold climate issues into guidelines and standards | Remove cold climate specific barriers |
| Content | Market study update; Validation of IEA Wind site ice classification | Ice sensor classification; Ice mapping | Work with IEC 61400-15 "Site assessment"; Develop and validate T19IceLossMethod software; Laboratory and full-scale testing; Ice protection system performance evaluation guidelines | International ice throw guidelines |
| Countries | ALL | Canada, Denmark, Finland, Sweden, Switzerland | ALL | Austria, Canada, Switzerland |
| Results | New cold climate practices to international standard IEC 61400-15 "Site assessment"; Market study updated; Maintain and update open source software "T19IceLossMethod"; International Ice Throw Guidelines; Updated Available Technologies report; Updated Recommended Practices report | | | |
| Outreach | Website; Workshops; Free software; Presentations at conferences | | | |

- WinterWind Conference, Piteå, Sweden [2]
- IWAIS 2015 "16th International Workshop on Atmospheric Icing of structures", 28 June–3 July 2015, Uppsala, Sweden [3]
- *WindPower Monthly* forum: Optimizing Wind Farms in Cold Climates, Helsinki, Finland [4]

At the WinterWind 2015 conference, a Task 19 pre-conference web survey was followed by a highly successful Task 19 panel discussion with industry guests. This session served as a basis for planning the IEA Wind Task 19 extension plan for 2016–2018. The session also highlighted the top three topic areas the research and industry community need to solve in order make better and faster progress in cold climate wind energy. A second Task 19 panel discussion was organized in the Optimizing Wind Farms in Cold Climates conference (Figure 2).

Two journal articles in the field of iced turbine vibration measurement and aeroelastic simulation analysis were submitted, which provided some breakthrough results. These results have been implemented in the new International Electro-Technical Commission (IEC) standard IEC 61400-1 "Design requirements of wind turbines" as new iced turbine design load cases [5, 6].

Three white papers were written in the field of low temperature climate chamber testing and icing (WindStats) and ice assessment best practices (*WindPower Monthly* magazine). Two task meetings were organized in 2015. The first meeting was held in Antwerp, Belgium, hosted by OWI LAB (SIRRIS). The second meeting was held in Aarhus, Denmark, hosted by Vestas.

Figure 2. Task 19 panel session at Optimizing Wind Farms in Cold Climates conference

## 4.0 Plans for 2016 and Beyond

The main goals of the year 2015 were to:

- Finish the report *Available Technologies for Wind Energy in Cold Climates*.
- Update the *Recommended Practices* report by verifying the recommendations, especially the cold-climate site classification, methods for energy yield estimation, and health and safety recommendations to coordinate safety regulations with respect to icing conditions (ice throw).

Task 19 will continue for a fifth term from 2016–2018 with the following highlighted topic areas (see Table 2 and the IEA Wind Task 19 website):

- Work directly with international IEC standards, more specifically the IEC 61400-15 "Site Energy Yield Assessment" with regard to low temperature and icing issues (a new focus area).
- Update the world market analysis for cold climates.
- Develop international ice throw risk assessment guidelines.
- Update and validate the T19IceLossMethod software.

Task 19 will hold two meetings in 2016, the first one in the UK in June, and the second one potentially in Norway in the fall (more detailed meeting schedule available at the Task 19 website).

**References:**

Opening photo: Wind energy in a cold climate (Photo Credit: A. Vignaroli, Source: VTT 2010)

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[6] Rissanen, S. et al., Modelling load and vibrations due to iced turbine operation. *Multi-Science Wind Engineering* (February 2016)

Author: Ville Lehtomäki, VTT Technical Research Centre of Finland, Ltd, Finland.

# 5 Task 25

## Design and Operation of Power Systems with Large Amounts of Wind Power

### 1.0 Introduction

Wind power introduces more uncertainty into operating a power system because it is variable and partially unpredictable. To meet this challenge, there is a need for more flexibility in the power system. How much extra flexibility is needed depends on the amount of wind power and the existing flexibility of the power system.

The existing targets for wind power anticipate quite a high share of generation from wind in many countries. Wind integration studies are important measures to make sure the anticipated amounts of wind power can be accommodated in a power system. In addition to studies, there is growing real-life wind integration experience emerging from some countries. Denmark, Ireland, and the Iberian Peninsula (Spain and Portugal) already show a high penetration of 20–40% of yearly electricity consumption coming from wind power.

Comparisons between integration study results are difficult to make because they use different methodologies, data, and tools, as well as different terminology and metrics, in representing the results. IEA Wind Task 25 has worked on summarizing results from its participating countries, as well as formulating recommendations on best practices for integration studies. Because system impact studies are often the first steps taken towards defining wind penetration targets within each country, it is important to apply commonly accepted standard methodologies in system impact studies.

The Task 25 website is at www.ieawind.org under Task Websites. The public portion of the site contains the Task 25 publications, as well as hourly time series of the wind power production database, a literature bibliography, contact details of participants, and the Task 25 work plan. The members-only section details the meeting presentations and information relevant to task participants.

In September 2005, Task 25 of the IEA Wind Implementing Agreement was approved for three years, 2006–2008, at Executive Committee (ExCo) meeting 56. The work was granted a fourth term from 2015–2017 at ExCo 74 in 2014. Table 1 shows the participants in the task. Since the initial 11 countries plus WindEurope (formerly the European Wind Energy Association) joined the first term, Canada, the Chinese Wind Energy Association (CWEA), Italy, and Japan have joined Task 25 in the second and third phases. France and México joined in the fourth term.

### 2.0 Objectives and Strategy

The ultimate objective of IEA Wind Task 25 is to provide information to facilitate the highest economically feasible wind energy penetration in electricity power systems worldwide. Task 25 work supports this objective by analyzing and further developing the methodology to assess the impact of wind power on power systems. Task 25 has established an international forum for the exchange of knowledge and experiences related to power system operation with large amounts of wind power. Transmission system operators (TSOs) also participate in the meetings.

Participants collect and share information on experience in wind integration and from current and past studies. Their case studies will address different aspects of power system operation and design: reserve requirements, balancing and generation efficiency, capacity credit of wind power, efficient use of existing transmission capacity, requirements for new network investments, bottlenecks, cross-border trade, and system stability issues.

The main emphasis is on technical operation. Also, technology that supports enhanced penetration will be addressed, such as wind power plant controls and operating procedures, dynamic line ratings, storage, and demand side management. Assessing costs has resulted in many discussions, as it is hard to find a fully transparent and cost-reflective way of allocating system-wide costs to a single technology.

The task work began with a state-of-the art report that collected the knowledge and results so far. This report, first published in 2007, has been updated in 2009 and 2013 and the next edition is expected to be published in 2016. This work has also been used to make best practice recommendations (IEA Wind recommended practices *RP16 Wind Integration Studies* was published in 2013) and fact sheets describing the integration issues in a simplified manner.

### 3.0 Progress in 2015

In 2015, a database collecting one year of hourly data from large-scale wind power production was published as an Excel sheet. Short

summaries of wind integration issues were published as fact sheets for general audiences. The main fact sheet is a four-page document illustrating the main issues, with linked two-page fact sheets for each topic. The literature list was updated, as an excel list but also available in Mendeley reference manager. The meetings organized by Task 25 have established an international forum for exchange of knowledge and experiences. The spring task meeting in 2015 was organized in Trondheim, Norway and hosted by Sintef. The autumn meeting, set to be hosted by EdF in Paris, had to be postponed to January 2016 because of the terrorist attacks.

Coordination with other relevant activities is an important part of the Task 25 effort. The system operators of Denmark, France, Italy, the Netherlands, and Quebec, Canada have been active in Task 25 in 2015. Task 25 follows the Institute of Electrical and Electronics Engineers (IEEE) activities in new working groups for flexibility and operation of power systems. In 2015, a new collaboration was started with IEA Photovoltaic Power Systems (PVPS) Task 14, and a joint meeting is planned for 2016.

Publication of the work is a key goal of Task 25 cooperative research. Collaborative papers on the following topics were published in 2015:

- Estimating $CO_2$ impacts of wind power (Holttinen, et al.), published/presented in *IEEE PES GM*, July 2015
- Variability in large-scale wind power generation (Kiviluoma, et al.), published at *Wind Energy*, Wiley, 2015
- Wind integration impacts in hydro dominated systems (Huertas Hernando, et al.), Accepted to Wiley's *WIRES*
- Capacity value of wind (Milligan, et al.), Revision to Wiley's *WIRES*
- Wind curtailments (Bird, et al.), Revision to *Renewable and Sustainable Energy Reviews*. Summary to WIW2015 Wind integration workshop (Yasuda, et al.)
- Power system stability issues (Flynn, et al.), accepted to Wiley's *WIRES*

In addition, the status and challenges of wind integration and results of IEA Wind Task 25 were presented at the first day integration panel of European Wind Energy Association (EWEA) in November 2015. Task 25 was represented, also with a poster, in Ireland at the UCD workshop on 23 November 2015.

#### 3.1 Wind power curtailments

Curtailed wind generation is one metric showing how well wind power can be accommodated by the power system. Experience on curtailments from several countries show the challenges of wind integration as a need to reduce available wind energy in critical moments (Figure 1). In addition, curtailments are often calculated from wind integration study simulations for power system dispatch.

The experience of wind power curtailments shows that curtailments do not occur when wind power represents small shares of yearly electricity consumption (5–10%). This is because there are no severe transmission bottlenecks and wind power is dispatched first among the low marginal cost generation (Quebec; Nordic countries; Portugal). In Spain, curtailments increased after reaching a 10% share of wind, but have remained at low levels after mitigation measures were in place. Altogether, curtailment remained at relatively low levels—below 1% of total wind generation. In some areas, substantial curtailments (10–20% of total wind generation) have started occurring at lower shares of wind (China, Italy, and the U.S. state of Texas). The mitigation efforts regarding transmission build out have resulted in a reduction in curtailment rates with increasing wind power.

In China, another reason for curtailments is due to surplus generation from must-run units like combined power and heat power plants operating according to heat load and prioritized generation from fixed tariffs with guaranteed full load hours to coal power plants.

In Figure 1, the left graph shows examples of countries with transmission network issues resolving as more wind power is added. The right graph shows examples of European countries showing little curtailment. Ireland has a larger proportion of small wind systems compared to other countries.

Table 1. Countries and Organizations Participating in Task 25 During 2015–2017

| | Country/ Sponsor | Organization(s) coordinating work in countries |
|---|---|---|
| 1 | Canada | Hydro Quebec/Hydro Quebec Research Institute (IREQ) |
| 2 | CWEA | State Grid Energy Research Institute (SGERI) |
| 3 | Denmark | Technical University of Denmark (DTU Wind), TSO Energinet.dk |
| 4 | Finland | VTT Technical Research Centre of Finland |
| 5 | France | Electricite de France (EdF) R&D, TSO RTE, Mines Tech |
| 6 | Germany | Fraunhofer Institute for Wind Energy and Energy System Technology (IWES); TSO Amprion |
| 7 | Ireland | University College Dublin (UCD); Sustainable Energy Authority of Ireland (SEAI) |
| 8 | Italy | TSO Terna |
| 9 | Japan | Tokyo University; Kansai University; Central Research Institute of Electric Power Industry (CRIEPI) |
| 10 | México | Instituto de Investigaciones Eléctricas (IIE) |
| 11 | Netherlands | TSO TenneT; Delft University of Technology (TUDelft) |
| 12 | Norway | SINTEF Energy Research |
| 13 | Portugal | Institute for Systems and Computer Engineering, Technology and Science (INESC TEC), National Laboratory on Energy and Geology (LNEG) |
| 14 | Spain | University of Castilla-La Mancha |
| 15 | Sweden | Royal Institute of Technology (KTH) |
| 16 | UK | Center for Distributed Generation and Sustainable Electrical Energy (DG&SEE) |
| 17 | United States | National Renewable Energy Laboratory (NREL), Utility Variable Generation Integration Group (UVIG), U.S. Department of Energy (DOE) |
| 18 | WindEurope | WindEurope (formally EWEA) |

Note: TSO is Transmission System Operator
International Council on Large Electric Systems (CIGRE) Joint Working Group (JWG) C1, 3, 6/18, IEA Secretariat in Paris, and European TSO consortium European Wind Integration study (EWIS) have sent observers to meetings.

### 3.2 Recommended practices for wind integration studies

The methods of conducting wind integration studies are evolving, building on experience from previous studies, accessing more data on system-wide wind power production, and applying improved models. Task 25 has made a recommendation report to compile the best practices and instructions on how to perform an integration study. A complete integration study includes several parts, which usually means an iterative process. Figure 2 shows this process as a flow chart, with relevant iteration loops from simulations to set-up and with portfolio development. Often wind integration studies only cover one or a few parts of a complete study.

Wind integration studies usually have a starting point of a set of input data (blue boxes, Figure 2). These data include (future) wind power plant location and output, data for other generation units, as well as data for electricity consumption and load. The portfolio development step is needed to set up the details of the system to be studied—the present or future system, assumed generation fleet and transmission network, demand and flexibility options available, and interconnection options to neighboring areas. The study identifies a wind penetration level of interest to be studied.

At the portfolio development stage, the scope of the system to be studied should be determined (i.e., the whole synchronous power system or a part of it). The basic setup assumptions have a crucial impact on the results of the study. For example, how the wind power is added—replacing something else or with the remaining generation staying the same—makes a difference. For lower contributions of wind power, the assumption that the remaining system stays the same can be used as a starting point. However, reaching higher contributions usually also means the conventional generation portfolio may change in the future system.

Changes in system management may need to be made from the start to accommodate large amounts of wind power. This involves checking the options for flexibility available in the power system through operational measures and through the transmission grid. Allocation, procurement, and use of reserves in a cost effective manner may also have to be changed.

Wind integration studies usually involve investigations of transmission adequacy, simulations of the operation of the power plants in the system, and calculations on the capacity adequacy to meet the peak load situations (the green boxes in the flow chart, Figure 2). A more detailed level includes dynamic simulations and a flexibility assessment—these are necessary when studying higher penetration levels of wind power. Reliability constraints from transmission, capacity adequacy, or reserve margins may require iteration on the initial results to change the installed capacity of the remaining power plants, the transmission grid, the operational methods, or the reserves.

Analyzing and interpreting results of wind integration studies is not straightforward. The assumptions made and the setups of the study, such as investments in the remaining system, are crucial to determining the integration impacts. Larger wind shares in the power system usually mean 10 to 30 years in the future, and the question is which other investments are to be performed in the power system during these years.

Integration costs are especially challenging to derive. Because system costs are difficult to allocate to any single plant or technology, wind integration studies aim to quantify the incremental increases in costs for power systems. One issue is grid reinforcement costs, with the allocation challenge that most grid upgrades also benefit other users. Most studies so far have concentrated on the technical costs of integrating wind into the power system. Another approach is cost-benefit analysis. The benefit of adding wind power to power systems is the reduction of the total operating costs and reduction of harmful emissions as wind replaces fossil fuels.

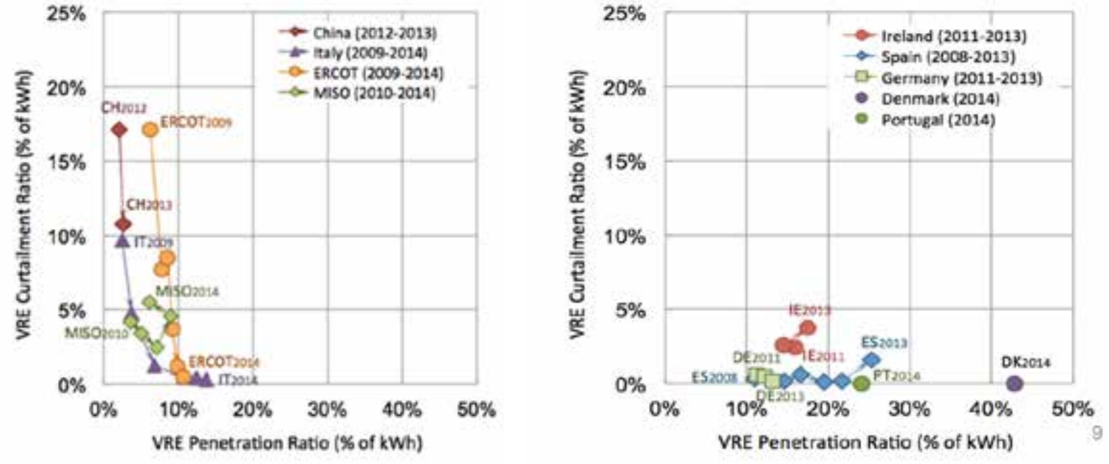

Figure 1. Experience of wind power curtailments

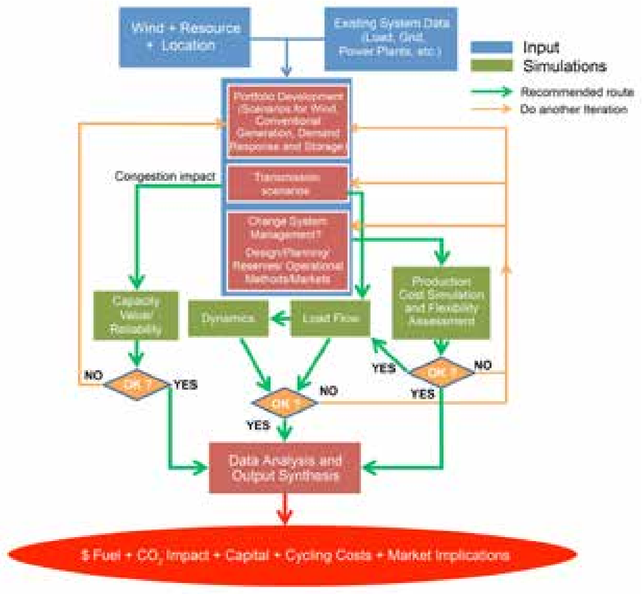

Figure 2. Flow chart of a complete wind integration study, showing relevant iteration loops from simulations to set-up and portfolio development

## 4.0 Plans for 2016 and Beyond

The spring meeting in 2016 will take place in May in Fredericia, Denmark, hosted by Energinet.dk. This will be a joint meeting with IEA PVPS Task 14 on grid integration. The fall meeting is planned for Glasgow and will be hosted by Strathclyde University.

The summary report from the 2012–2014 phase will be published in 2016. Journal articles and conference presentations will be drafted about critical modeling issues in wind integration studies, such as comparison of studies with high shares of wind energy, integration costs, planning and operational time scale modeling, electricity market design, curtailments, forecast error modeling, and dynamic reserve requirements.

IEA Wind Task 25 work and results are expected to be presented at several meetings: the IEEE PES summer conference in July 2016 and the Wind Integration Workshop 2016 (WIW16) in Vienna, Austria. Task 25 work will also be presented in national conferences in Austria (March 2016) and Ireland (April 2016).

**References:**

Opening photo: Task 25 Wind Integration Factsheets (2015)

Author: Hannele Holttinen, VTT Technical Research Centre of Finland, Finland.

# 6 Task 26

## Cost of Wind Energy

## 1.0 Introduction

**Wind power generation costs have dropped to a point where they are competitive with conventional generation costs in some cases. Technology development is intended to reduce the cost of energy, but recent market drivers, including fluctuations in commodity and fuel prices, also impact the cost of energy. Wind energy costs differ among countries and comparison is difficult. The scope of IEA Wind Task 26 is to assemble and analyze estimates of past, present, and future wind energy costs using transparent, consistent methodologies.**

**In the first phase of Task 26, January 2009 through May 2012, a common spreadsheet model to estimate cost of energy was developed and used by participants to illustrate cost of energy differences among participating countries for projects installed in 2008 [1]. Analysis of historical trends in the cost of energy and assessment of future projections for the cost of energy were also conducted [2]. Participants also discussed concepts for defining and quantifying the value of wind energy.**

**The second phase of the task officially began in October 2012 and concluded in September 2015. In this phase of the task, continued investigation of land-based wind cost of energy resulted in a common format to present project-level data that contributes to cost of energy calculations and illustrate trends from 2007 through 2012 [3]. Updated estimates of cost of energy from 2008, 2012, and anticipated near-term projects are also included this report. Investigation of approaches to assess the cost of offshore wind energy and to understand cost drivers and differences among participating countries has led to development of a common baseline project representation and a cash flow model for quantifying differences. An expert workshop on the value of wind energy in a system context, as well as a survey of experts on future cost of energy perspectives were conducted in this phase of the task [4, 6].**

**Due to the continuing in understanding the aspects of the wind industry that affect the cost of land-based and offshore wind technologies, a third phase of Task 26 began in October 2015 and will continue through September 2018.**

## 2.0 Objectives and Strategy

The objective of Task 26 is to provide information on cost of wind energy in order to understand past and present, and to anticipate future trends using consistent, transparent methodologies as well as understand how wind technology compares to other generation options within the broader electric sector.

Expected results for Task 26, phase 2, period October 2012 through September 2015 included:

- Enhanced international collaboration and coordination in the field of cost of wind energy
- Updated data, analysis, and understanding of land-based wind energy cost trends and comparison among countries
- Identification of the primary offshore wind energy cost drivers and the variation of these costs among participating countries
- Collaborative journal articles summarizing and further analyzing work conducted to understand trends in cost of energy
- Collaborative journal articles exploring issues related to the value of wind energy.

In 2015, eight IEA Wind Members representing 12 distinct organizations with participation from over 20 individuals are continuing to contribute to IEA Wind Task 26 in 2015. The IEA Wind Task 26 Members and participating organizations are shown in Table 1.

## 3.0 Progress in 2015

In 2015, efforts were focused in three areas: 1) publication of a report detailing land-based wind energy cost and performance trends as well as cost of energy estimates among participating countries; 2) collaboration among participating countries to assess offshore wind data and information needed to estimate the cost of offshore wind energy; and 3) implementation of a survey of wind energy experts to elicit perspectives on future cost reduction potential for land-based, fixed-bottom offshore, and floating offshore wind technologies.

### 3.1 Cost of land-based wind energy

Wind plant technology, cost, and performance trends from 2008 through 2012 were collected and presented for Denmark, Germany, Ireland, Norway, European Union, and the United States (a future update to this work will include wind projects in Sweden). Using methods developed in prior work [1], Levelized Cost of Energy (LCOE) estimates for 2008 and 2012 were created to illustrate trends. Excerpts from this work, published June 2015 [3], are presented here.

The primary elements required to estimate LCOE include capital investment cost, expected annual energy production, expected annual operation costs, and project financing costs. "Typical" or "average" characteristics of all projects installed in a given year in a given country are represented. Each wind project is unique such that there is significant variation in all of the primary parameters and thereby significant variation in LCOE. However, these estimates provide an indication of general trends over the period from 2008 to 2012:

- Capital investment costs reached a peak around 2010 and have declined in most countries since then despite the increased wind turbine size. This trend is most evident in Denmark and the United States. Although Germany, Ireland, and Norway did not demonstrate this decline in 2012, it may be realized in the near term and is expected based on estimates for 2014 projects in Norway.
- Energy capture increases for typical wind plants are reported by all countries, particularly for good or high wind speed locations. In some cases (e.g., Germany and the United States), utilization of lower quality resource sites offsets expected increases in full load hours or capacity factors.
- Operation and maintenance costs anticipated over the life of a wind plant are not well understood and project cost data are lacking. It is not clear whether these costs are increasing or decreasing on average.
- Project finance costs expressed as the Weighted Average Cost of Capital (WACC) have generally remained flat over this period in Denmark, Ireland, and Norway. Germany and the United States report reduced WACC from 2008 to 2012 [7].

As illustrated in Figure 1, LCOE based on the above high-level trends results in a mixed picture for the countries represented in this analysis with both increasing and decreasing LCOE values from 2008 to 2012 [3]. Initial indications since 2012 suggest a trend toward lower cost of energy through 2014 and beyond. Note that these LCOE estimates do not reflect any revenue or policy incentives and assume a 20-year depreciation schedule for comparison among countries. These LCOE estimates reflect the cost to develop, construct, and operate a wind plant from the perspective of a developer and or owner.

A variety of revenue and policy incentives are utilized in each of the countries represented in this study. The combination of expected revenue for electricity sales and policy incentives provides the developer or owner of a wind project with means to recoup the cost of building the wind plant (i.e., the LCOE). The feed-in tariff (FIT) was the predominant support scheme for wind energy in EU Member states during the 2008–2012 time period. Recently, several countries have begun phasing out FIT schemes in favor of tender schemes or market certificate schemes. The United States continues to favor a tax-based policy.

Semi-annual meetings provide a valuable forum for exchanging ideas among the participants and engaging with other industry or research organizations. For example, a launch event associated with the land-based wind cost of energy publication held in Copenhagen, Denmark, in June 2015, included presentations and discussion from a number of Danish industry, government, and academic perspectives. This informal information exchange is highly valuable to the task overall, as well as for the participating national organizations.

### 3.2 Cost of offshore wind energy

Because the cost of offshore wind energy is very site-specific and currently concentrated in a small number of markets, an approach for consolidating data among participating countries was devised. Data

**Table 1. Countries and Organizations Participating in Task 26 in 2015**

| | Country/ Sponsor | Organization(s) |
|---|---|---|
| 1 | Denmark | Denmark Technical University (DTU), Ea Energy Analyses |
| 2 | EU | European Commission – Joint Research Centre |
| 3 | Germany | Deutsche WindGuard, Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) |
| 4 | Ireland | Dublin Institute of Technology (DIT) |
| 5 | Netherlands | TKI Wind-op-zee |
| 6 | Norway | Norwegian Water Resources and Energy Directorate (NVE), SINTEF Energy Research |
| 7 | UK | Offshore Renewable Energy (ORE) Catapult |
| 8 | United States | National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL) |

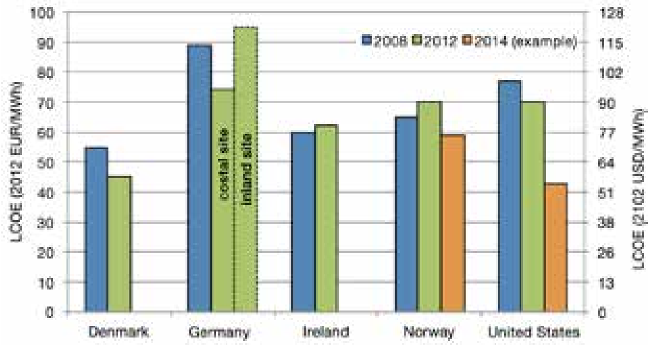

Figure 1. LCOE trend from 2008 to 2012 with some 2014 examples [3]

and model estimates for existing and planned offshore wind projects were combined and compared. A baseline representation of the physical characteristics of a typical offshore wind plant was developed [5].

This approach allows for analysis of cost drivers based on information provided from the various participants and will represent offshore wind project costs generically—rather than specifically to those countries where projects are in operation. Using this baseline, each of the participating countries will explore country-specific deviations in market and policy conditions in order to identify and quantify both technical and policy-based cost drivers.

### 3.3 Future cost of wind energy perspectives

IEA Wind Task 26 investigates the current state and cost of wind energy technologies and how costs might evolve in the future. One method for quantifying future cost of energy perspectives is expert elicitation, asking structured questions of top experts in the field. Task 26 participants surveyed top experts in the field about their perspectives on future cost of energy for land-based, fixed-bottom offshore, and floating offshore wind systems [6]. This is the first large-scale global expert elicitation survey on future wind energy costs and related technology advancements, and with over 160 experts participating, is the largest known elicitation ever performed on an energy technology in terms of expert participation. Some key findings are shown in Figure 2.

Ultimately, this work intends to inform policy and regulatory communities on future cost reduction potential, provide high-level input into electric sector modeling assumptions, and highlight R&D opportunities.

## 4.0 Plans for 2016 and Beyond

In 2015, a task extension proposal was approved by the Executive Committee. The task extension includes the following activities over the subsequent three years (October 2015 through September 2018). Statistical trends in wind plant and turbine technology, cost, and performance will be published annually. The format devised in prior work to present the statistical range of data reflecting projects in a given country is easily updated and will provide a mechanism for more current representation of the basic cost of energy parameters going forward. A report exploring trends in technology, wind plant resource conditions, project cost elements, and refined cost of energy estimates is planned for 2018.

Exploration of offshore wind cost drivers, both technical and policy-related, will continue. Methodologies to compare the impact of these drivers are under consideration. A publication of baseline offshore wind plant characteristics will occur in 2016 followed by an analysis of cost drivers and country-specific impacts.

Results from the expert survey on future cost of wind energy will be published in 2016 in the form of reports as well as conference presentations.

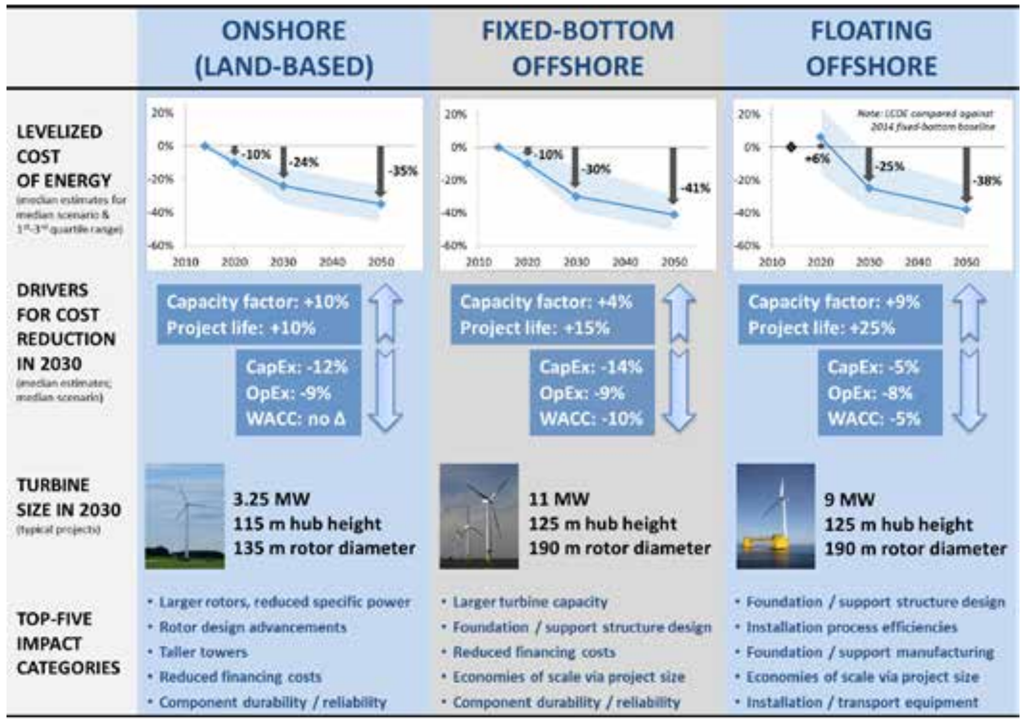

Figure 2. Summary of expert survey findings on future cost of wind energy [6, 9]

A new work package will be initiated to explore the value of wind energy in the electric sector. As wind energy quantities increase, time-varying prices fluctuate. Modeling analysis to understand how wind plant technology options can affect this price variation will be conducted.

In addition to these specific work packages, regular meetings will be held to stimulate collaboration among the participants, resulting in additional publications at conferences or in journals. Progress can be followed on our website (www.ieawind.org/ task_26.html).

### References and notes:

Opening photo: Task 26 meeting, Oslo, Norway, Norwegian Energy and Water Resources Directorate, October 2015 (Photo credit: Liv Arntzen Løchen, NVE). Pictured from left to right: Gavin Smart (Offshore Renewable Energy Catapult, U.K.), Iver Bakken Sperstad (SINTEF Energy Research, Norway), Volker Berkhout (Fraunhofer Institute for Wind Energy and Energy System Technology, Germany), Aaron Smith (National Renewable Energy Laboratory, U.S.), Leif Husabø (Norwegian Water and Energy Resources Directorate, Norway), Aisma Vitina (EA Energy Analyses, Denmark), David Weir (Norwegian Water and Energy Resources Directorate (Norway), Daniel Beals (U.S. Department of Energy, U.S.), Mark Higgins (U.S.Department of Energy, U.S.), Maria Stenkvist (Swedish Energy Agency, Sweden), Maureen Hand (National Renewable Energy Laboratory, U.S.).

[1] Schwabe, P.; Lensink, S.; Hand, M. (2011). *IEA Wind Task 26 - Multi-national Case Study of the Financial Cost of Wind Energy; Work Package 1 Final Report*. 122 pp.; NREL Report No. TP-6A20-48155. Download from www.nrel.gov/docs/fy11osti/48155.pdf and ieawind.org/task_26.html

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[7] After-tax, nominal WACC = (1-Debt share)*Return on equity + Debt share*Return on debt*(1- Corporate tax rate); After-tax, real WACC = ((1+nominal WACC)/(1+inflation rate))-1

[8] In Figure 1, the LCOE estimate for Denmark is based on a wind project where grid connection costs are socialized; the estimate for Germany in 2008 represents a good average wind site rather than distinguishing between coastal or inland sites; the 2014 estimate for Norway represents wind plant technology anticipated for installation in 2014 and beyond; the 2014 estimate for the United States is an example of wind project characteristics associated with very low prices contracted in 2012-2013 for projects in the interior region of the country with relatively high annual average wind speed.

[9] All dates are based on the year in which a new wind project is commissioned. LCOE and LCOE drivers are shown relative to 2014 baseline values. Rather than assume that all experts have the same internal 2014 baselines, we offered a default option but allowed experts to provide their own estimates for land-based and fixed-bottom offshore wind. Roughly 80% of experts opted to use the default baseline values. We did not seek a 2014 baseline estimate for floating offshore wind; floating offshore wind changes are therefore compared to expert-specific 2014 baselines for fixed-bottom offshore wind.

Author: Maureen Hand, National Renewable Energy Laboratory (NREL), United States.

# 7 Task 27

### Development and Deployment of Small Wind Turbine Labels for Consumers (2008–2011) and Small Wind Turbines in High Turbulence Sites (2012–2016)

## 1.0 Introduction

**Small wind turbines provide electric power in remote and peri-urban windy areas and offer an important potential for distributed applications. The interest in distributed wind generation—the use of small wind turbines to produce clean energy for individual homes, farms, and small businesses—is growing at a rapid pace. With this technology, people are able to generate their own power, reduce their external energy supply, cut their energy bills, and help protect the environment.**

**Most small wind turbines are not designed for roofs, the built environment, or urban settings because anything blocking the wind in the dominant wind direction creates high turbulence, the most difficult wind condition for wind turbines of all sizes.**

**The main goals of IEA Wind Task 27 are to offer the opportunity to share technical experience on measuring and modeling urban and peri-urban wind resources, learn about emerging trends, and gain practical experience on turbine performance.**

**Task 27 work on wind turbines in high turbulence sites started late in 2012 with a planned duration of four years and was extended one year to the end of 2017. Documentation of the task activities is proceeding through the development of case studies which are intended to capture technical findings and research results.**

**The five Working Packages (WPs) are as follows:**

- **WP 1: Deploy Small Wind Association of Testers (SWAT) consumer label**
- **WP 2: Analyze and model a highly turbulent wind resource**
- **WP 3: Collect "new" wind resource and turbine power performance data from rooftop and complex terrain test sites**
- **WP 4: Develop a Recommended Practice on micro-siting of small turbines in highly turbulent sites**
- **WP 5: Prepare for standards by developing a new approach to vertical axis wind turbine (VAWT) simplified loads methodology (SLM) and conduct other multi-year research needed to improve the fourth revision of the International Electrotechnical Commission (IEC) standard: (IEC 61400-2).**

## 2.0 Objectives and Strategy

The work will require analyses of existing three-dimensional wind resource data and collection of new data, combined with analyses and computational fluid dynamics (CFD) models to provide an understanding of turbulent inflow. The goal is to begin to comprehend how turbulence impacts small wind turbine production and whether turbulence is appropriately characterized in the IEC 61400-2 standard. Case studies, technical results, papers, and presentations can be used as a basis for the IEC 61400-2 Maintenance Team 2 (MT2) to consider for revising the standard, currently scheduled to begin after 2018.

The objectives and expected results are:

- Develop an IEA Wind Recommended Practice on Micro-siting of Small Wind Turbines in Highly Turbulent Sites that provides guidelines, trends, and information on micro-siting of small turbines in highly turbulent sites (urban and peri-urban settings, rooftops, in forested areas, etc.).
- Provide research results and case studies to the future IEC MT2 as technical background and for consideration in revising IEC 61400-2 parameters such as I15 requirements, external conditions, normal turbulence model, extreme direction change, VAWT SLM, and icing considerations, amongst others.
- Compile case studies for each research or test activity conducted. This includes developing and validating CFD models for simple structures and shapes and rooftop test sites, characterizing the wind resource in areas of high turbulence (rooftop, peri-urban, urban, etc.), and evaluating the impact of turbulence on turbine performance in peri-urban sites.
- Promote the technical exchange of small wind turbine testing approaches and methodologies through the SWAT.
- Develop a consumer label based on IEA Recommended Practice "Consumer Label for Small Wind Turbines" and IEC 61400-2 third revision, informative annex.

The task expects to publish a document summarizing their case study research results and findings, including:

- Measured and modeled wind resource and turbulence parameters ($I_{15}$ or similar variables, normal turbulence models, extreme direction change, and others)
- CFD model results of simple experiments and test sites
- Turbine production results in various areas with high and low turbulence
- Comparison of field and accredited test site power performance results
- Preliminary VAWT SLM and other inputs to IEC 61400-2.

## 3.0 Progress in 2015

### 3.1 IEA Wind Task 27 meetings

During 2015, Task 27 activity was significant. Six meetings were conducted, which included four virtual meetings and two face-to-face meetings. The first two virtual meetings (VM #11 and VM #12) were held on 26 January (27 January in Asia) and the second two virtual meetings (VM #13 and VM #14) were held on 22 July (23 July in Asia). Sixteen experts from Australia, Austria, Argentina (observer), China and Taiwan, Denmark, Ireland, Republic of Korea, Spain, and the United States attended the first virtual meetings. Ten experts from six countries (Austria, China, Ireland, Republic of Korea, Spain, and the United States) participated in the second virtual meetings. All virtual meetings were hosted by the National Renewable Energy Laboratory (NREL).

The University of Applied Sciences Technikum Wien hosted the first face-to-face meeting in Vienna, Austria on 14 and 16 April at the

**Table 1. Countries and Organizations Participating in Task 27 During 2015**

| | Country/Sponsor | Organization(s) |
|---|---|---|
| 1 | Austria | University of Applied Sciences Technikum Wien (UASTW) |
| 2 | CWEA | Chinese Wind Energy Association (CWEA) |
| 3 | Denmark | Danish Technical University (DTU) |
| 4 | Ireland | Dundalk Institute of Technology (DKIT) |
| 5 | Japan | National Institute of Advanced Industrial Science and Technology (AIST) |
| 6 | Korea | Korea Institute of Energy Technology Evaluation and Planning (KETEP) |
| 7 | Spain | Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT) |
| 8 | United States | National Renewable Energy Laboratory (NREL) |
| | México (New partner in 2016) | Centro Mexicano de Innovación en Energía Eólica (CEMIE-Eólico) |
| | Argentina (Observer) | Instituto Nacional de Tecnología Industrial (INTI) |
| | France (Observer) | Centre Scientifique et Technique du Bâtiment (CSBT) |

# 7 Task 27

Figure 1. IEA Wind Task 27 meeting attendees at the Department of Renewable Energy of the University of Applied Sciences Technikum Wien, Austria (Photo credit: Ignacio Cruz)

Department of Renewable Energy (Figure 1). Fifteen experts attended this meeting representing eight countries: Austria, Australia (observer) China, Denmark, Germany (observer), Ireland, Spain, and the United States; fourteen presentations were given. On 17 April 2015, the Austrian Small Wind Energy Association hosted a meeting at the university facilities. Additionally, a meeting of the IEC RE WE-OMC WG502 small wind turbine subgroup was held the following morning, 16 April 2015.

NREL hosted the second face-to-face IEA Wind Task 27 meeting of 2015 at the National Wind Technology Center (NWTC) on 9–11 September in Louisville, Colorado, United States (Figure 2).

More than 20 experts participated—many from the United States, but also some from Austria (virtual), Argentina (virtual), Australia (virtual), China, Ireland, Japan (virtual), Republic of Korea, and Spain. Over 30 presentations were given on unaccredited and accredited testing of small wind turbines, national standards and certification schemes, new results from CFD studies of built-environment wind turbines, new approaches to gathering yaw measurements for built-environment wind turbine testing, and lessons learned from small wind turbine testing.

This meeting was followed by the Fourth Annual SWAT Conference on 14–16 September 2015 at the NWTC, also in Colorado, United States.

## 3.2 Technical results summary

### 3.2.1 CFD model results

Dr. Francisco Toja (CIEMAT, Spain) gave a presentation focused on the results of a CFD simulation of the wind flow around buildings with the case study of a CEDER-CIEMAT building in Soria. Measurements were collected at the Soria site to validate the CFD simulations. The turbine's location on the roof may be an important factor in determining rooftop wind viability. For this reason a detailed CFD study is planned using a mesh with small cells very close to the building. Large eddy simulation (LES) was considered, but was determined to be too expensive, therefore, Reynolds-averaged Navier–Stokes (RANS) models were applied instead.

Figure 2. IEA Wind Task 27 attendees at the NREL-NWTC (Photo credit: Ignacio Cruz)

Ms. Hildegard Kaufmann and Dr. Kathrin Baumann-Stanzer (Zentralanstalt für Meteorologie und Geodynamik, Austria) presented on the climatological aspects and wind flow simulation for Vienna. This presentation showed the results of the application of INCA, a numerical weather prediction model for Austria with a resolution of 100 x 100 m that has been validated with an extended observational network and use of SOnic Detection and Ranging (SODAR) for urban areas. The model was validated based on measurements using heated ultrasonic anemometers.

Dr. Jonathan Whale (Murdoch University, Australia) presented on using CFD to gain insight into the turbulence inflow conditions for a small wind turbine on a building rooftop. This study assessed the combination of a CFD package and wind atlas software as a wind resource assessment tool for a small wind turbine installation on a rooftop in the built environment. The tool was used to investigate wind speed and direction on the rooftop and identify the optimal location for installing the turbine, taking into account zones of wind acceleration, recirculation, and blockage.

The results of the study show CFX, a CFD program, provides reasonable accuracy for simulating flow around a rectangular obstacle and the combination of a CFD package with a wind atlas software, such as WAsP, provides a promising tool for wind resource assessments for small wind turbines on buildings. The model used the Kaimal filter with a standard deviation found in urban environment. There seems to be much better correlation for 5 m/s winds.

Dr. Liu Shuquin (Shandong University, China) gave a presentation on the wind field around a rectangular CFD model of a flat roof. A roof with a turbine shows areas of flow disruption. If multiple turbines are to be placed on a roof, the downstream turbines should be placed at least 4 m higher than upstream turbines.

Dr. Renate Teppner (Austria Institute of Technology, Austria) gave a presentation on two projects, IPPONG and STEP-A. IPPONG uses CFD for optimal positioning of small wind turbines in urban areas. The roof and surroundings areas were modeled with measurements points at the roof's four corners, which were assumed as boundary conditions. The CFD model simulated seven wind directions and estimated performance using a cubic function of simplified geometry. The structured surge cases use an annual average, which is the basis of an estimation of energy yield. The resulting plot can influence where to place a turbine on the roof.

The second project, STEP-A, studies the economic potential of small wind turbines. Focusing on the CFD part of this project only and based on a dominant wind direction, the building's impact on the flow can be modeled. The model estimates boundary layer thickness of city structures and gives guidance on the needed turbine height to get above the boundary layer of the roof. Based on FLUENT, general-purpose CFD software package, time-independent simulations can be evaluated using wind speed and wind directions can be simulated in MISCOM.

### 3.2.2 Turbulent-site test results

Dr. Chin-Jen Chang (INER, Taiwan) gave a presentation on high-rise rooftop testing at National Taiwan University; reporting a capacity factor on the roof of 0.09%. Professor Lee from the National Taiwan University collected and analyzed rooftop measurements on using three-dimensional sonic anemometers.

Dr. Seokwoo Kim (KETEP, Republic of Korea) gave a presentation on rooftop testing on Jeju Island for a site surrounded by water on three sides. Initial results show turbulent kinetic energy is almost double in the direction where the wind comes over the building before it sees the three-dimensional anemometer.

Mr. Jason Fields (NREL, U.S.) presented on the progress of the case study of the NASA Johnson Space Center Building 12 in Houston, United States. Relevant recommendations for the built-environment wind turbine measurement were provided, including resource assessment and turbine response. Very low wind speeds were found on this low-rise building, as well as very low capacity factors, all less than 0.01%.

Mr. Kurt Leonhartsberger (UASTW, Austria) presented an approach to evaluating a VAWT and horizontal axis wind turbine in an urban rooftop environment (ENERGYbase) and a rural environment (Energy Research Park in Lichtenegg; Figure 3). The ENERGYbase site uses SODAR (100 m away from the roof) and two-dimensional measurements to characterize the wind resource and better understand the effects of turbulence. Lichtenegg is an open, small wind turbine test site with rolling hills. Meeting participants visited the site during face-to-face meeting #14. Test results gathered at Lichtenegg and at the ENERGYbase will be the basis of comparison of production and turbulence characteristics.

Mr. Davide Conti (DTU, Denmark) set up a "fence experiment," a two-dimensional structure to validate wind resource measurements with WaSP. Two sonic anemometers were used to create the wind profile and wind direction on both sides of the fence. Currently the fence is made with wood and has a 100% blockage; but wood can be removed to create a lower blockage level.

### 3.2.3 Peri-urban turbulent production

Mr. Raymond Byrne (DKiT, Ireland) gave an overview of the Irish small wind turbine field test data and presented a comparison. All data for wind speed and wind direction were two-dimensional measurements with a 1-minute sample rate. There are 16 Sustainable Energy Authority of Ireland (SEAI) small wind turbine datasets for different turbine models, all sited in different peri-urban sites. Data sets were chosen to minimize the turbine effects and maximize site comparison. Two data sets were analysed to show variations in site turbulence levels: a good site with an $I_5$ of 0.18 and $I_{15}$ of 0.16 and a

Figure 3. IEA Wind Task 27 meeting participants visit the small wind test site Energy Research Park in Lichtenegg, Austria operated by the University of Applied Sciences Technikum Wien (UASTW) Department of Renewable Energy (Photo credit: Ignacio Cruz)

poor site with an $I_5$ of 0.21 and $I_{15}$ of 0.18. Task 27 experts have been discussing whether an $I_5$ is a better turbulence parameter for active small wind turbines compared to an $I_{15}$.

Mr. Jason Fields (NREL, U.S.) presented an interesting case study of four wind turbines roof-mounted on a high-rise in Portland, Oregon, United States. These turbines were located directly above penthouse units and integrated into the building design early with extensive pre-construction resource assessment. Based on the production data, the four small wind turbines had a 7% capacity factor. The building owners still consider the project successful because of the positive recognition the building received.

### 3.2.4 Complex terrain prediction methods

Dr. Jia Yan (Inner Mongolia University of Technology, China) gave a presentation on ARCGIS, a tool that can handle complex terrain and provide turbine production predictions. Mr. Jason Fields (NREL, U.S.) gave a summary of a distributed wind resource assessment meeting and indicated that model-based approaches currently account for the majority of the industry's effort to understand a site's wind resource. While measurements are important and valuable, the challenges with cost and deployment time currently preclude widespread adoption of measurement campaigns.

### 3.2.5 Technical results for fourth revision of IEC 61400-2

Further progress is being made by Dr. Su Wei-nian (INER, Tiawan) on developing a new approach for a VAWT simplified load methodology and then validating this approach with measurements. This effort is focused on two VAWT configurations: Darrieus and Savonius small wind turbines.

## 3.3 Publications, presentations, and agreements

### 3.3.1 Publications

Bashirzadeh Tabrizi, A., Whale, J., Lyons, T. and Urmee, T. (2015) *Extent to which international wind turbine design standard, IEC61400-2 is valid for a rooftop wind installation*, Journal of Wind Engineering & Industrial Aerodynamics, 139. pp. 50-61.

Bashirzadeh Tabrizi, A., Whale, J., Lyons, T., and Urmee, T. (2015) *Rooftop wind monitoring campaigns for small wind turbine applications: Effect of sampling rate and averaging period*, Renewable Energy, 77, pp. 320 – 330.

Bashirzadeh Tabrizi, A., Whale, J., Lyons, T., Urmee, T., and Peinke, J. (2015) *Assessing the effect of an adapted Kaimal turbulence model on the structural loading of small wind turbines in highly turbulent sites*, American Wind Energy Association WindPower 2015 Conference and Exhibition, Orlando, Florida, May 18 – 21.

F. Toja-Silva, F., Peralta, C., López, O., Navarro, J., Cruz, I.. (2015) *Roof region dependent wind potential assessment with different RANS turbulence models*, Renewable Energy, under review.

F. Toja-Silva, F. (CIEMAT), Peralta, C. (F-IWES), Lopez, O. (UPM), Navarro, J., Cruz, I. (CIEMAT). (2015) *Roof region dependent wind potential assessment with different RANS turbulence models*, Journal of Wind Engineering & Industrial Aerodynamics. 142, Pages 258–271.

Toja-Silva, F., Peralta, C., Lopez-Garcia, O., Navarro, J., Cruz , I. (2015) *On the roof geometry for urban wind energy exploitation in high-rise buildings*, Computation, in press.

### 3.3.2 Presentations

*Task 27 Small Wind Turbines in High Turbulence Sites*, Cruz, I., Forsyth, T., Austrian Wind Energy Association Small Wind Conference Viena,15 April 2015.

*Task 27 Small Wind Turbines in High Turbulence Sites*, Cruz, I., Forsyth, T., 2015 European Wind Energy Conference EWEA – IEA Wind Side Event, November 2015.

### 3.3.3 Agreements

An agreement was proposed with the World Wind Energy Association Small Wind division to implement the small wind turbine label on the www.small-wind.org website. Republic of Korea plans to use the Recommended Practice consumer label as a starting point for certification requirements in that country.

An agreement was proposed with the SWIP Project (www.swip-project.eu) to exchange data and procedures with IEA Wind Task 27. The SWIP project seeks "new innovative solutions, components and tools for the integration of wind energy in urban and peri-urban areas," (EU FP7).

## 4.0 Plans for 2016 and beyond

The following are plans for 2016 and beyond:

- Develop Recommended Practice *Micrositing of Small Wind Turbines in Areas of High Turbulence*
- Draft case studies on measurement campaign, CFD model results, and peri-urban turbine production
- Develop CFD models for the Danish fence experiment and the U.S. NASA Johnson Space Center rooftop test site
- Compare turbulent field site turbine performance to accredited turbine performance results
- Continue to study the effects of different roof shapes on the wind conditions.

**References:**

Opening photo: Xzeres Skystream 3.7 small wind turbine for rural applications sited in Waterford, Ireland, SEAI Irish field trial (Photo credit: CREDIT Dundalk IT)

Authors: Ignacio Cruz, CIEMAT, Spain and Trudy Forsyth, Wind Advisors Team, United States.

# 8 Task 28

## Social Acceptance of Wind Energy Projects

## 1.0 Introduction

Founded in 2008, IEA Wind Task 28 has highlighted the importance of considering social acceptance issues when planning and implementing wind power projects. Reports, results, and projects from Task 28 are available for free download at: www.socialacceptance.org.

Task 28 was the first non-technical Task within IEA Wind and was initiated because wind power was meeting growing opposition in many countries. While wind power is an important pillar in many energy policies and renewable energy strategies worldwide, garnering acceptance for projects from communities and non-governmental organizations has proven to be a challenge.

Between 2012 and 2016, seven countries participated in Task 28 (Table 1). In the first phase of Task 28 (2008 to 2011), a comprehensive State-of-the-Art Report was published on acceptance knowledge gained from research and literature as well as the specific experiences in the participating countries. This was possible because of the strong interdisciplinary mix of experts from the planning, regulating authorities, industry, and research disciplines. The analysis was based on the three dimensions established by Wüstenhagen et al. (2007)—socio-political, market, and community acceptance. The report covered issues that are still proving relevant: policy and strategies, well-being and ecosystems, distributional justice, procedural design and implementation strategies. Recommendations for the inclusion of social acceptance issues in planning indicate that there is no single approach to gain social acceptance, but several successful strategies and aspects must be carefully taken into account. Task 28 took up new issues arising within the acceptance of wind, such as offshore and wind in woodlands.

The main issues of the second phase (2012 to 2015) were "monitoring social acceptance" and the role of "positive intermediaries." For monitoring, an analysis of possible requirements and available monitoring programs was elaborated and indications for possible activities in the context of IEA Wind were discussed. For positive intermediaries, the focus was on analysis of various case studies and description of role models. Working group meetings were held in conjunction with expert meetings on wind power and social acceptance in most participating country.

## 2.0 Objectives and Strategy

IEA Wind Task 28 supported participating countries and institutions by:

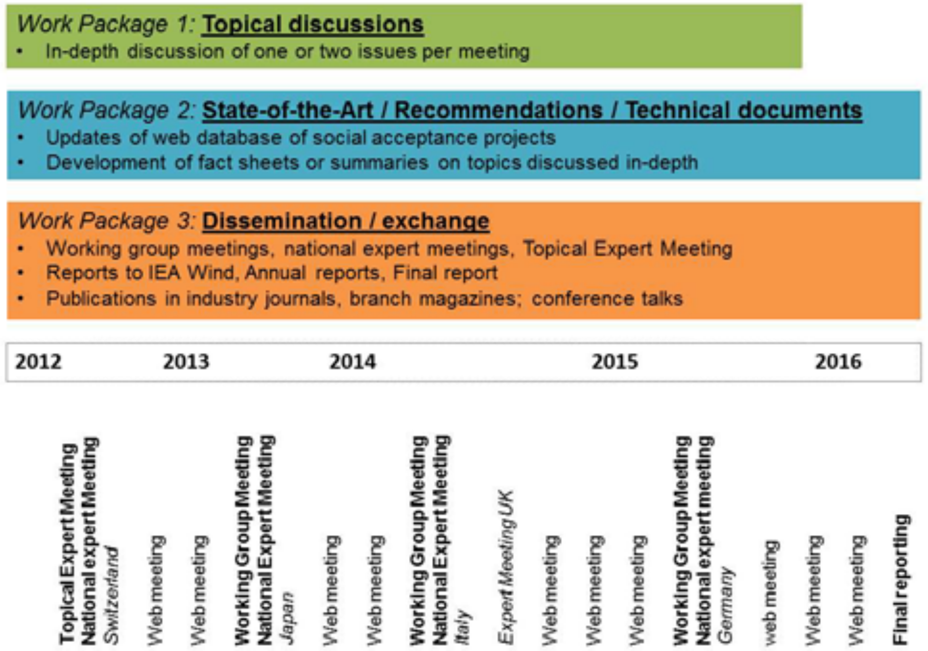
- Providing up-to-date information on social acceptance of wind energy in the participating countries.
- Identifying and documenting successful policy strategies anticipated to be applicable across other local contexts.
- Enabling sharing of practical information, learning from each other, complementing each other's approaches.
- Discussing the complex issues around social acceptance and gaining additional insights from the broad transnational and interdisciplinary experience of the Task 28 network.
- Working together on open issues and research gaps, including opportunities for joint research.
- Enlarging the network and knowledge of best practices by institutions, organizations, experts, and practitioners.
- Providing reports, publications, and presentations in the language of planners, developers, authorities, and other stakeholders outside the research community who need to be informed on the issues to be able to develop successful projects.

In 2012, 40 participants attended the task kick-off meeting hosted by the Swiss Federal Office of Energy in conjunction with a Task 11 Technical Expert Meeting. In 2013, 100 experts attended an expert group and working group hosted by the Japan Electrical Manufacturers' Association. In 2014, 40 participants attended a meeting hosted by RSE Ricera sul Sistema Energetico in conjunction with an Italian expert meeting.

## 3.0 Progress in 2015

Task 28 held a working group meeting in Berlin, Germany, in June 2015 with German wind organizations: Stiftung Offshore Windenergie (Offshore Association), Fachagentur Windenergie an Land (Agency for Wind Energy on Land), Bundesverband Windenergie (Germany Wind Energy Association). Additional participants included guests from the Joint Research Centre of the European Union and its E-track project, the WindEurope (formerly European Wind Energy Association) and its WISE Power project, as well as guests from the Netherlands (Pondera Consulting NL) and Turkey (METU Center for Wind Energy). The meeting was connected to a national expert meeting by the German Federal Ministry for Economic Affairs and Energy. The meeting brought together presentations from international experts from Task 28 and German experts presenting projects promoting the German "Energiewende," or energy transition.

The in-person meeting was in addition to several web meetings during the year addressing preparation, project updates, and documentation activities. These meetings were used to finalize the analyses of "monitoring and assessment" and "positive intermediary." Task 28 participants are working on drawing conclusions and recommendations to include within a working paper and the final report.



## 4.0 Plans for 2016 and Beyond

The final report for the second phase of IEA Wind Task 28 will be completed in the spring 2016. The final report will include technical appendices for both the "positive intermediary" and "monitoring and assessment" topics.

Task 28 members have begun discussions on continuation of the international and interdisciplinary exchange of the last eight years. While all members of the Task 28 working group emphasize the added value of extending the Task, tangible results are hard to describe and recommendations are perceived as less objective than for more technical tasks. A new proposal is expected to be presented to the IEA Wind Executive Committee in autumn 2016.

Authors: Markus Geissmann, Swiss Federal Office of Energy and Stefanie Huber, ENCO Energie-Consulting AG, Liestal, Switzerland.

**Table 1. Participating Countries in Task 28 between 2012 and 2016**

| | Country/ Sponsor | Organization(s) |
|---|---|---|
| 1 | Denmark | Danish Energy Agency; Technical University of Denmark (participating since 2014) |
| 2 | Germany | Federal Ministry for the Environment, Nature Conservation and Nuclear Safety; Martin Luther University; University of the Saarland |
| 3 | Ireland | Sustainable Energy Authority; Queen's University Belfast |
| 4 | Italy | RSE Ricerca Sistema Energetico |
| 5 | Japan | National Institute of Advanced Industrial Science and Technology; Nagoya University |
| 6 | Switzerland | Federal Department of the Environment, Transport, Energy and Communications, Swiss Federal Office of Energy; ENCO Energie-Consulting AG, |
| 7 | United States | U.S. Department of Energy; National Renewable Energy Laboratory Wind Technology Center; Lawrence Berkeley Lab |

# 9 Task 29

## Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models (Mexnext I, II, and III)

## 1.0 Introduction

It is well known that modeling wind turbine response (i.e., the power, load, and stability) is subject to large uncertainties. Many code validations show that most of these uncertainties come from aerodynamic modeling [1]. This is not surprising given that every aerodynamic problem is covered by the "Navier Stokes" equations, which cannot be solved in an exact way. A good illustration of the extreme complexity of fluid dynamics, specifically aerodynamics, is that it is the subject of one of the seven millennium prize problems established by the Clay Mathematics Institute of Cambridge, Massachusetts (see www.claymath.org/millennium-problems/millenniumprize- problems).

Within the class of aerodynamic problems, wind turbine aerodynamics falls within the outer category in terms of uncertainties because wind turbines are exposed to very complex aerodynamic phenomena such as 3-D geometric and rotational effects, instationary effects, yaw effects, and stall effects. Moreover, the huge size of wind turbines adds complexity through large blade deflections, a very inhomogeneous inflow, and very thick airfoils [2].

The availability of high-quality measurements is the most important prerequisite to gaining insight into these uncertainties and validating and improving aerodynamic wind turbine models. At first sight, full-scale measurements seem to be preferred for this purpose. However, full-scale field experiments alone cannot answer all the questions because they suffer from large uncertainties caused by the stochastic atmosphere in which the wind turbines operate. As such, insights gained from full-scale field measurements have to be combined with insights from wind tunnel measurements, which are taken in a well-known, controlled environment.

The need for high-quality aerodynamic data was the most important reason for initiating IEA Wind Task 29 Mexnext. The first phase, Mexnext-I, ran for three years, beginning June 2008. The main goal of Mexnext-I was to analyze the measurements from the European Union (EU) *Mexico* project (Model Rotor Experiments in Controlled Conditions) [3]. Ten institutes from six countries cooperated in experiments on an instrumented, three-bladed 4.5-m wind turbine placed in the largest (9.5 by 9.5 $m^2$) European wind tunnel at the German-Dutch Wind Tunnels Large Low-speed Facility (DNW-LLF) in the Netherlands.

Measurements taken in December 2006 resulted in a database of combined blade pressure distributions, loads, and particle image velocimetry (PIV) flow field measurements, which could be used for aerodynamic model validation and improvement. Mexnext-I benefited from 20 participants in 11 countries and ran through 2011 [4]. Thereafter, a second phase, Mexnext-II, was approved and ran from January 2012 until December 2014 with 21 partners from 10 countries [5].

One of the key activities in Mexnext-II was an inventory of *all* the historical aerodynamic wind turbine measurements—where history ranges from long ago to very recent and includes the *Mexico* experiment. Another key activity in Mexnext-II was the *New Mexico* experiment, again carried out in the DNW-LLF on the model wind turbine from the Mexico project. These New Mexico measurements aimed to answer several outstanding research questions from the Mexico experiment, to validate and compliment the experiment taking into account the lessons learned, and to cover new research priorities defined in Mexnext-I.

An extensive test matrix was followed which combined pressure and load measurements with PIV measurements, but this time with a wider PIV range. In addition, microphone array measurements and several flow visualization techniques were applied. The measurements were taken under a variety of conditions, often complementary to the conditions covered in Mexico. Other measurements were performed at yaw and/or dynamic pitch, standstill, and faulty large pitch misalignments using International Electrotechnical Commission (IEC) Aerodynamics relevant for calculations according to the standards [6].

The New Mexico experiment was completed in July 2014 leaving only five months remaining in the term for analysis. Therefore, a third phase of IEA Wind Task 29 was initiated, Mexnext-III, which runs from January 2015 until December 2017. The main objective of Mexnext-III is to analyze the New Mexico measurements. Detailed aerodynamic measurements from other experiments are included as well.

The Operating Agent of IEA Wind Task 29, Mexnext, is the Energy Research Center of the Netherlands (ECN) (see Table 1).

## 2.0 Objectives and Strategy

The objective of IEA Wind Task 29 Mexnext is to form a more complete understanding of wind turbine aerodynamics thereby improving aerodynamic models used for wind turbine design. The improvements are based on the New Mexico experiment and other public field and wind tunnel measurements. Mutual cooperation and information exchange between aerodynamic experts worldwide is another important objective.

The approach in Mexnext-III is very similar to the approach followed in Mexnext-I and Mexnext-II. It includes an inventory of unexplored experiments in addition to the New Mexico experiment. Data are processed, presented, and assessed on uncertainties and, if applicable, tunnel effects; calculational results from the codes used by the participants are compared with the data from the various experiments.

The final area of focus in Mexnext-III investigates a variety of specific aerodynamic phenomena including 3-D and unsteady effects, yawed flow, non-uniformity of the flow between the blades (i.e., tip corrections), boundary layer transition, and flow devices. These phenomena are investigated with isolated sub-models, simple analytical tools, or by physical rules. IEC aerodynamics and acoustics have become important areas of investigation within Mexnext-III as well.

## 3.0 Progress in 2015

In March 2015, the kick-off meeting of Mexnext-III was held in Amsterdam, the Netherlands. This meeting was attended by almost all participants, each presenting their plans for Mexnext-III activities. A thorough assessment of the New Mexico data was conducted and then the measurements were released to the Mexnext participants. The data are shared on the so-called Beehub facility of the Dutch Surfsara. This facility provides a general storage service for large datasets and easy sharing with collaborators. The database was accompanied by a detailed description of the experiment and the database and a report describing the data reduction and analysis [7, 8].

A new calculational round was carried out using the New Mexico measurements as a basis. The conditions were more or less comparable to the conditions for which calculations were performed in Mexnext-I (i.e., aligned flow at approximately 10, 15, and 24 m/s), but in the present case, clean airfoil data were used for the outer part where tripped airfoil data were used in Mexnext-I. Moreover, some participants took into account the tower and nacelle geometry.

Although in some cases a considerable spread between load calculations were found, the results are now more or less evenly distributed around the measurements. This was opposite to the situation in Mexnext-I where all codes resulted in an over-prediction. It is

**Table 1. Countries and Organizations Participating in Task 29 During 2015**

| | Country/ Sponsor | Organization(s)* |
|---|---|---|
| 1 | CWEA | Chinese Wind Energy Association (CWEA) |
| 2 | Denmark | Danish Technical University (DTU) |
| 3 | France | CORIA, EDF, ONERA, IFPEN |
| 4 | Germany | Fraunhofer IWES, University of Stuttgart (IAG), University of Applied Sciences at Kiel, ForWind, Windnovation, German Aerospace Laboratory DLR, Enercon |
| 5 | Japan | Mie University/National Institute of Advanced Industrial Science (Mie/AIST) |
| 6 | Netherlands | Energy Research Center of the Netherlands (ECN), Delft University of Technology (TUDelft), Suzlon Blade Technology (SBT), and the University of Twente, Det Norske Veritas-Germanischer Loyd (DNV-GL) |
| 7 | Norway | Institute for Energy Technology/Norwegian University of Science and Technology (IFE/NTNU) |
| 8 | Sweden | Uppsala University Campus Gotland |
| 9 | United States | National Renewable Energy Laboratory (NREL) |

*Technion in Israel is a subcontractor to Task 29.

encouraging to note that clear progress towards the goal of calculations that closely match experimental data has been identified compared to the situation in Mexnext-I. This is best illustrated through Figures 1 and 2.

Figure 1 shows a comparison from Mexnext-I between the behavior engineering model (BEM) calculations and the Mexico measurements of the sectional chord normal force as function of radial position at two tunnel speeds: 10 m/s and 15 m/s. The differences are great, especially at the most important outer part of the blade. Figure 2 shows the Mexnext-III comparison with New Mexico experiment measurements in much better agreement. This illustrates progress in the predictions even at the turbulent wake state at 10 m/s. In this complex flow situation, the first round of calculations in Mexnext-I still suffered from numerical problems.

Another sign of progress is that more high fidelity models, which require limited CPU-time in comparison to full computational fluid dynamics (vortex wake, actuator line), are used in Task 29. Not shown in this report are the comparisons on flow field data, which generally also show a good agreement. Work has also been done, led by DNV-GL, focusing on specific research areas, and interesting results have been obtained on faulty pitch conditions. For these cases, blade two is operating at a 20-degree pitch off-set. The effect of this off-set pitch is apparent in the pressure distribution of blade one, with a non-affected pitch angle, offering a very interesting test case for modelers (Figure 3).

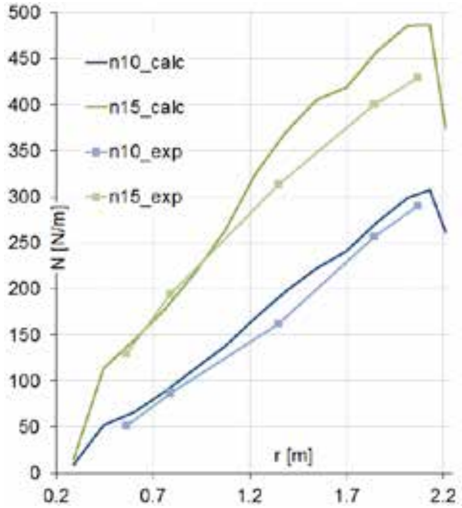


Figure 1. Comparison between BEM load calculations and Mexico load measurements, results from Mexnext-I (2008)

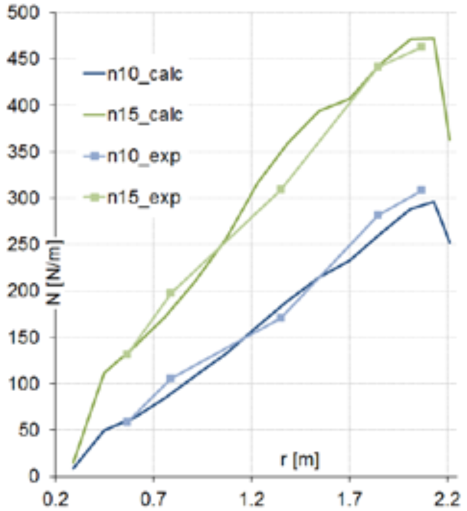


Figure 2. Comparison between BEM load calculations and Mexico load measurements, results from Mexnext-III (2015)

Note that, until now, results have been published and presented in numerous papers and articles. A long list of references is given in the *Final report of IEA Wind Task 29: Mexnext (Phase 2)* [5] where recent examples are given in other publications [9-14]. Mexnext also formed the basis for two PhD theses [15, 16] and the wind tunnel data served for code validation proposes in a number of further PhD theses. Another very importantmeans of dissemination of Mexnext information is through education—information from Mexnext is used in many lectures at universities.

## 4.0 Plans for 2016 and Beyond

In January 2016, a meeting was held at NREL in the United States in combination with an IEA Wind Topical Expert Meeting on aerodynamics organized by IEA Wind Task 11.

In the coming term, much attention will be paid to the comparison between calculations and measurements. Although Figure 1 and Figure 2 show a considerable improvement compared to Mexnext-I, the large spread in the calculated load results needs to be better understood. The project group concluded that several of these differences are explained by post-processing issues, misunderstandings of definitions, grid issues, etc., which obscure the analysis and explanation of results. For these reasons, a second iteration of calculations will be complete by March 2016. All participants will clearly describe any changes applied to the calculations or process as compared to their first results. The new results and the next calculational cases (probably at yawed conditions) will be discussed in June 2016 at an intermediate Mexnext meeting prior to the AVATAR EU project meeting in Glasgow, Scotland.

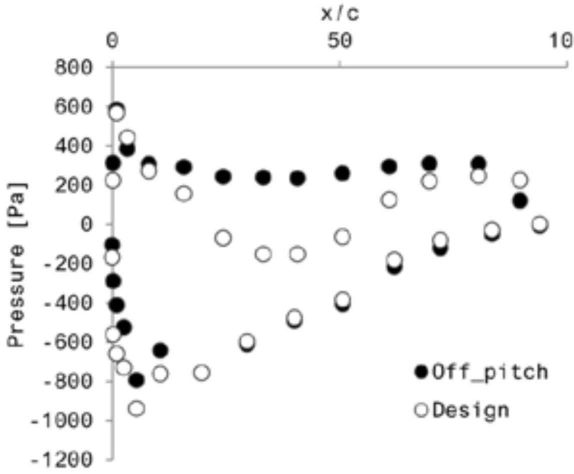


Figure 3. Pressure distribution on blade one with and without faulty pitch angle of blade two (courtesy of Luca Oggiano, IFE)

The participants in Task 29 will continue to focus on specific aerodynamic phenomena. This work will include the analysis of "other than New Mexico data," e.g., measurements and the underlying information on the experiment carried out by the Aeronautical Research Institute of Sweden (FFA) in the large Chinese Aerodynamics Research and Development Center (CARDC) tunnel at the end of the 1980s [17]. Also of interest are the PIV data on a 1/8 scaled model of the NREL Phase VI turbine, which were provided by CWEA and CARDC in December 2014. These data will be compared to the original data from the NREL Phase VI experiment, which were heavily analyzed in the past under IEA Wind Task 20.

Dissemination of results will be accelerated in 2016. Amongst others, several abstracts have been submitted to the Science of Making Torque conference in 2016. A journal article on aerodynamic measurements for the WIRES Energy and Environment Journal is under preparation as well.

Finally, the Mexico wind tunnel model will be shipped to the large 12 m x18 m CARDC wind tunnel. Measurements in this completely different tunnel configuration—the CARDC tunnel is closed where the DNW tunnel is open—will shed more light on tunnel effects.

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Opening photo: New Mexico experiment smoke visualizations in Large Low-Speed Facility (LLF) (9.5 x 9.5 m2) of German-Dutch Wind Tunnel (DNW) (photo credit: T. Westra)

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# 10 Task 30

## Offshore Code Comparison Collaboration, Continued, with Correlation (OC5)

## 1.0 Introduction

**Vast offshore wind resources represent a potential to use wind turbines installed offshore to make a significant contribution to the world's energy supply. Design of offshore wind turbines can be complicated because offshore sites vary significantly through differences in water depth, soil type, and wind and wave severity, which requires the use of a variety of support structure types. These types include fixed-bottom monopiles, gravity bases, space-frames (such as tripods and lattice frames or "jackets,") and floating structures. In this context, the offshore wind industry faces many new design challenges.**

**Wind turbines are designed and analyzed using simulation tools (i.e., design computer codes) capable of predicting the coupled dynamic loads and responses of the system. Land-based wind turbine analysis relies on the use of aero-servo-elastic computer codes, which incorporate wind-inflow, aerodynamic (aero), control system (servo), and structural-dynamic (elastic) models in the time domain in a coupled simulation environment. In recent years, some of these codes have been expanded to include the additional dynamics pertinent to offshore installations, including incident wave characteristics, sea currents, hydrodynamics, and foundation dynamics of the support structure. The high complexity and sophistication of these simulation codes underscores the need to verify and validate their accuracy.**

**The IEA Wind Offshore Code Comparison Collaboration (OC3) operated under Subtask 2 of the IEA Wind Task 23 Offshore Wind Energy Technology Deployment. OC3 was established to meet the need of model verification. Task 23 was completed in 2009. In 2010, a new IEA Wind Task was established to continue the work. The new task, Task 30, was called the Offshore Code Comparison Collaboration, Continued (OC4) and ran from 2010 to 2013 under the joint leadership of the National Renewable Energy Laboratory (NREL) and the Fraunhofer Institute for Wind Energy and Energy Systems Technology (IWES).**

**The OC3 and OC4 projects were successful in showing the influence of different modeling approaches on the simulated response of offshore wind systems. Comparisons to measured data, however, will ensure that the solutions accurately represent physical behavior. To address this need for model validation, an extension of Task 30 called Offshore Code Comparison Collaboration, Continued, with Correlation (OC5) was initiated in 2014.**

**The Task 30 extension (OC5) has now finished its second year, during which 122 people from 58 organizations in 16 countries have either joined the task or attended meetings as observers (see Table 1 and Table 2). Many more have participated via e-mail communication, but have not been able to attend physical meetings.**

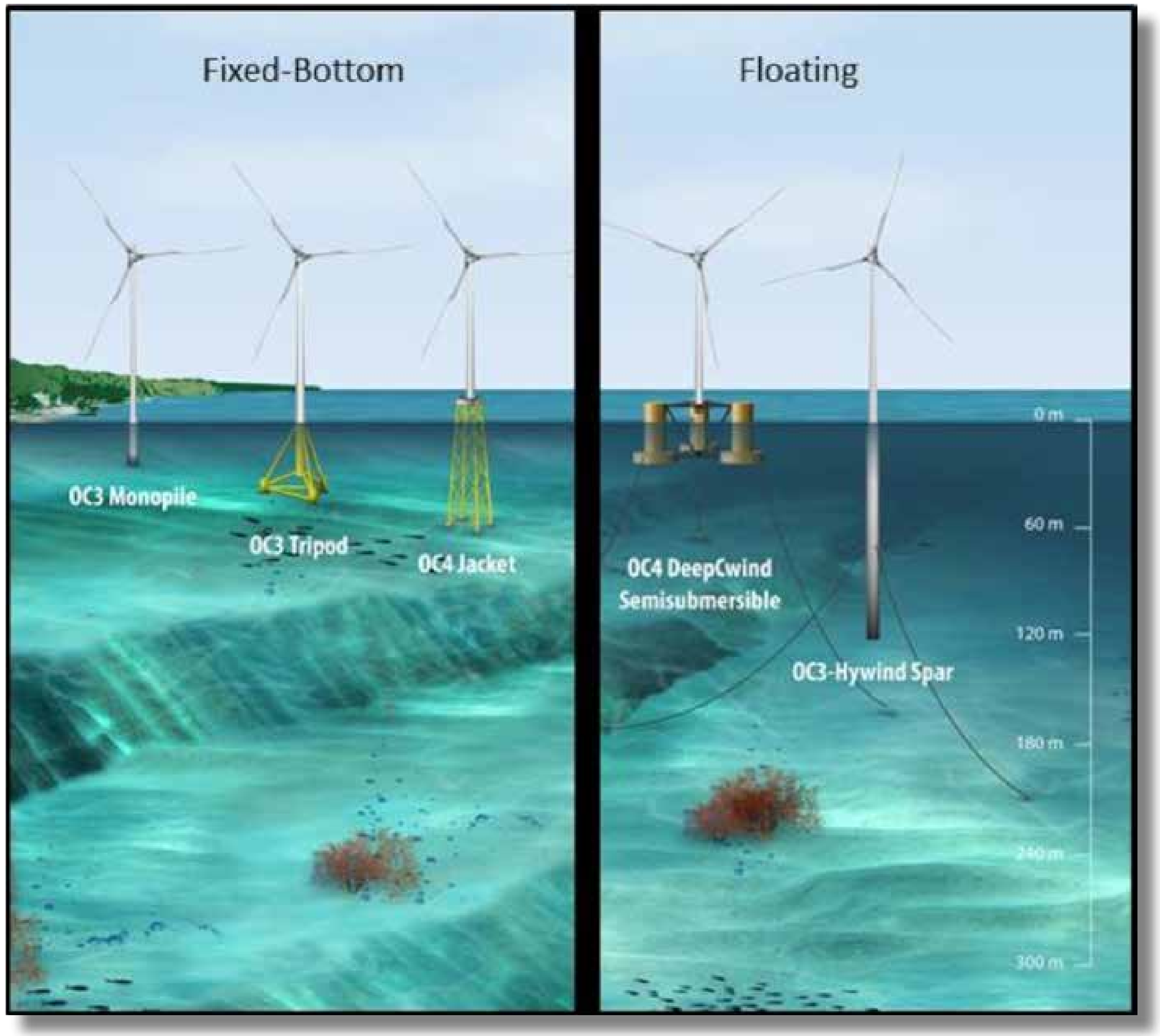
## 2.0 Objectives and Strategy

The purpose of the Task 30 OC5 project is to perform a benchmarking exercise of offshore wind turbine dynamics computer codes. To test the codes, the main activities of OC5 are to (a) discuss modeling strategies, (b) develop a suite of benchmark models and simulations where corresponding physical data exists, (c) run the simulations and process the simulation results, and (d) compare the results in a side-by-side fashion to the physical response data.

These activities fall under broader objectives including:

- Assessing the accuracy and reliability of simulations to establish confidence in their predictive capabilities,
- Training new analysts to run and apply the codes correctly,
- Identifying, verifying, and validating the capabilities and limitations of implemented theories,
- Investigating and refining applied analysis methodologies,
- Identifying further R&D needs.

The past verification work by OC3 and OC4 has led to dramatic improvements in model accuracy as the code-to-code comparisons and lessons learned have helped identify deficiencies and needed improvements in existing codes. The OC5 extension will further the accuracy assessment by comparing these simulated responses to response data recorded from actual offshore wind systems (a process called validation). The data used in this validation process will come from existing projects and will not be produced by OC5.



OC5 will contain a total of three different phases (see Figure 1). The offshore wind system concepts to be examined will not deviate far from those examined in the previous OC3 and OC4 tasks (while the concepts will be similar, the design details will change). The OC3 and OC4 projects, however, all contained the same wind turbine model, the NREL 5-MW reference turbine. Because we will be modelling real systems in OC5, each system will have a different wind turbine.

Phase I examined two different datasets, both consisting of tank tests of cylindrical members rather than data from a wind turbine. This was done initially to focus on the hydrodynamic modeling approaches and to provide an easy first step for establishing appropriate validation practices to be used throughout the project extension.

Phase II is re-examining the DeepCwind semi-submersible that was modelled during Phase II of OC4; the previous experience with this design is easing the validation process. The project is using data obtained from the testing of a 1/50th-scale model of the semi-submersible at MARIN in May of 2013. Numerous tests were performed ranging from simple free-decay tests to complex operating conditions with irregular sea states and dynamic winds.

Phase III will use data obtained from a deployed open-water offshore system at full scale. The Task is seeking permission from the Alpha Ventus project to use their jacket design. If this system is not available for OC5, other alternatives will be sought.

Significant differences are expected in the validation approach used for these different types of systems and data, as well as significant differences in the challenges encountered. Tank test data provides good

**Table 1. Countries and Organizations Participating in Task 30 During 2015**

| | Country/ Sponsor | Organization(s) |
|---|---|---|
| 1 | CWEA | China General Certification Center, Goldwind, Dongfang Electric Corporation |
| 2 | Denmark | DTU Wind Energy, DHI, DONG, University of Aalborg |
| 3 | France | EDF, INNOSEA, DCNS, IFPEN, Ideol |
| 4 | Germany | Fraunhofer IWES, University of Stuttgart SWE, Senvion, Leibniz Universität Hannover, WindGuard Certification, Ramboll |
| 5 | Italy | Polytechnico Di Milano, Ricerca Sistema Energetico (RSE), University of Florence |
| 6 | Japan | University of Tokyo, WEIT, ClassNK |
| 7 | Korea | University of Ulsan, Jeju National University |
| 8 | Netherlands | Energy Research Centre of the Netherlands (ECN), The Knowledge Centre WMC, MARIN |
| 9 | Norway | Norwegian University of Science and Technology , Institute for Energy Technology, Marintek, 4Subsea, University of Stavanger, Simis |
| 10 | Portugal | Wave Energy Centre, EDP, CENTEC |
| 11 | Spain | ALSTOM Wind, CENER, IH Cantabria, Tecnalia |
| 12 | United States | ABS Consulting, National Renewable Energy Laboratory, University of Maine, Penn State University, Texas A&M University, Lehigh University, University of Idaho |

**Table 2. Countries and Organizations Observing in Task 30**

| | Country | Organization(s) |
|---|---|---|
| 1 | Ireland | University College Cork |
| 2 | Singapore | Nanyang Technical University |
| 3 | Taiwan | Institute of Nuclear Energy Research |
| 4 | UK | DNV GL, Lloyd's Register, FloWave, University of Glasgow |

measurements of the excitation to the system, which is important in the validation process, but inherently requires a scaled model, which will not necessarily capture the appropriate full-scale physics. Full-scale system data provides more true physical responses, but is much more difficult to accurately measure the environmental conditions causing those responses.

## 3.0 Progress in 2015

OC5 finished its second year and is approximately half-way completed with the project. During 2015, Phase I was completed including the analysis of two different datasets from wave tank testing containing a fixed cylinder without a wind turbine. The first dataset (Phase Ia) was supplied by Marintek and consisted of a series of tests of individual suspended cylinders of varying diameters. The results from work with this dataset were summarized in a paper presented at the International Society of Offshore and Polar Engineers (ISOPE) Conference in June 2015 [1].

The second dataset analyzed (Phase Ib) was supplied by DTU/DHI and considered a cylinder tested in a wave tank affixed to a sloped floor. This dataset differed from the previous one analyzed in that the cylinder was fixed to the floor of the basin, was flexible, and had more wave nonlinearities due to the shallower depth and sloped floor. These differences allowed the group to focus on different features of the modeling tools.

Phase II of the project was initiated in 2015. In the last few months of the year, participants constructed models of the semi-submersible and performed initial calibration of the model through free-decay and wind-only simulations. Meanwhile, development work is progressing to ensure that the information needed for Phase III is obtained. Detailed specifications of the Alpha Ventus turbine (the REpower 5M) have been provided to OC5 by the manufacturer, Senvion. Discussions with OWEC Tower are ongoing concerning the availability of the jacket support structure design data. An application to access the measurement data from the project was submitted to the Research at Alpha Ventus (RAVE) consortium.

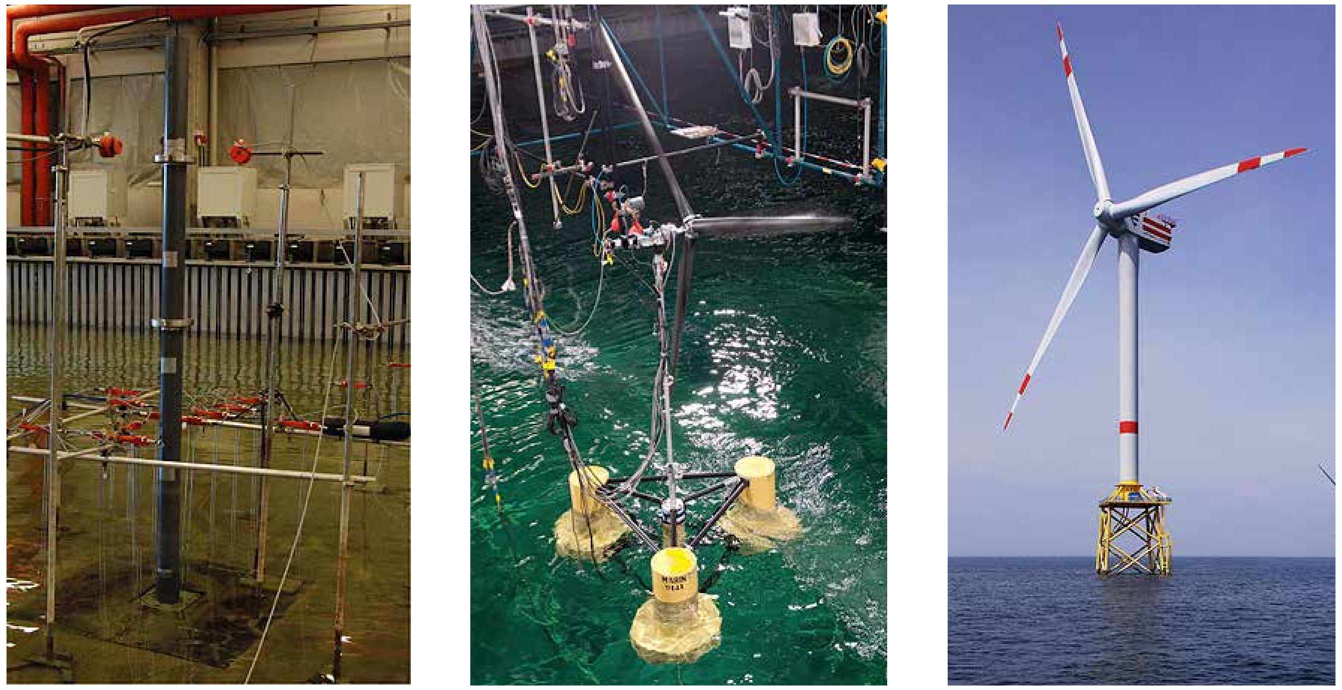
OC5 held a total of seven teleconferences throughout 2015 and had two bi-annual, in-person meetings—one at the DeepWind conference in Norway in February, and another at the ISOPE conference in Hawaii in June.

## 4.0 Plans for 2016 and Beyond

Project work for Phase II will continue during 2016 with an expected completion of the phase by the end of the year. Participants will run a complete set of load cases including wind-only, wave-only, and combined wind and wave simulations for the floating semi-submersible, and validate the simulated results against measurements from tank testing of the system. A summary paper of the work will be written, to be presented in 2017.

Also during 2016, project organizers will develop the information needed for the final phase of the project (Phase III), which will examine data from the Alpha Ventus system, a fixed-bottom, open-ocean, offshore wind demonstration project. Project work by participants on Phase III will be initiated either at the end of 2016 or beginning of 2017.

The next OC5 in-person meeting will take place at the DeepWind conference in Norway in January, 2016. At that meeting, results from the initial calibration work performed for Phase II using free-decay and wind-only simulations will be examined. In addition, a presentation will be given at the conference summarizing findings from Phase Ib of the project.


(a) Phase I:
Monopile—Tank Testing
June 2014–December 2015

(b) Phase II:
Semi—Tank Testing
January 2015–December 2016

(c) Phase III:
Open Ocean Test
January 2016–May 2017

Figure 1. Offshore wind system designs examined in Task 30 OC5

The second in-person meeting of 2016 will occur at the ISOPE conference in Greece in June, at which further results from Phase II will be discussed. In addition, a planning meeting for Phase III will be conducted in conjunction with the Torque conference in October, 2016 in Germany. The purpose of this meeting will be to meet with the research group, RAVE, in charge of the data from the Alpha Ventus project.

The verification activities performed in OC3 and OC4 are important because the advancement of the offshore wind industry is closely tied to the development and accuracy of dynamics models. OC5 continues this important work by focusing on validation using physical data measurements. Not only are the experiences and knowledge exchanged among the project participants vital, but the lessons learned have and will continue to help identify deficiencies in existing codes and needed improvements, which will be used to improve the accuracy of future predictions.

**References:**

Opening photo: Support structure types considered in Task 30 OC5

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# 11 Task 31

## WAKEBENCH: Benchmarking Wind Farm Flow Models

## 1.0 Introduction

Wind power meteorology is building the bridge between engineering models and atmospheric science. State-of-the-art wind resource assessment and wind farm design techniques are related to the characterization of large-scale climatology, mesoscale meteorological processes, microscale terrain and wind farm array effects, and wind turbine aerodynamics [1]. The spatio-temporal scales range from hundreds of kilometers to meters and from decades to milliseconds. Due to the breadth of the system, these four topics have been traditionally analyzed separately and this has given rise to different independent research communities (meteorologists, wind engineers, aerodynamicists). As a result, a wide variety of models are developed by each specialized group with little interaction with the neighboring communities.

Current wind energy models often lead to over-prediction of wind plant performance leading to high uncertainties and significant financial losses in the wind industry. A more accurate understanding of the physical processes in wind farms and better models are required for industry to quantify and mitigate risks in wind turbine siting. The next generation of wind energy models will necessarily have an integrated approach that produces a more comprehensive characterization of the modeling system. This interdisciplinary, integrated approach will lead to better understanding of the physical response of wind turbines and therefore, more opportunities for design optimization and cost-of-energy reduction.

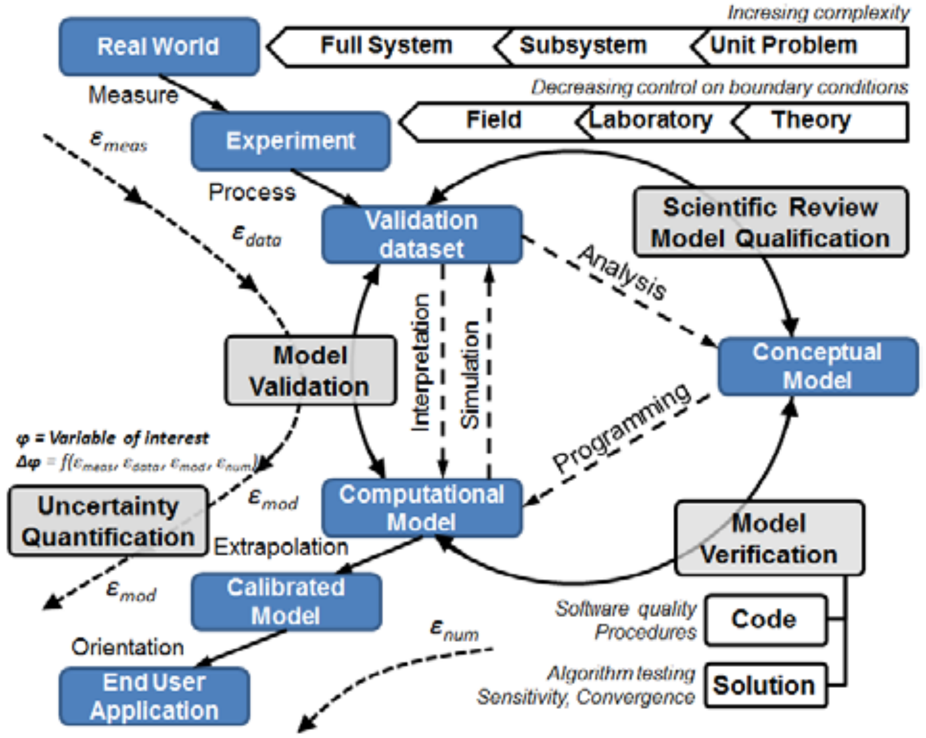
Nevertheless, building the bridge between the spatio-temporal scales of the different stages of the model chain is a challenging task for various reasons: cross-cutting knowledge is needed across a wide range of atmospheric and engineering sciences; models that have been developed separately must be integrated, large computational resources are required, and high-quality experimental data is lacking that can span all the relevant scales in order to validate the downscaling process and quantify uncertainties.

The standard practice in wind farm siting makes use of computational fluid dynamic (CFD) models, with different levels of simplification, to solve the microscale flow around and within wind farms. At the engineering level, turbulence modeling is still largely based on Reynolds-Averaged Navier Stokes (RANS) approaches. RANS approaches are used due to their cost-efficiency compared to large-eddy simulation (LES) models that may be more realistic but are far more costly. In non-homogeneous terrain, surface-layer models in neutral conditions are typical choices. However, as wind turbines get larger, such a micro-scale approach needs to adopt atmospheric boundary layer (ABL) models. ABL models account for the vertical structure of turbulence up to the geostrophic wind including thermal stratification (or atmospheric stability) effects.

Wind farm wake models also range in complexity depending on the level of detail of rotor and flow physics, from algebraic actuator-disk to full-rotor CFD models. While array efficiency models are heavily focused on reproducing the far-wake at downwind distances of 5D or more, there is increasing interest in introducing better modeling of the transition and near wake regions where rotor aerodynamics are important. This is not only to improve array efficiency predictions but also to gain access to reliable wind turbine loading data that can be additionally used in the wind farm design process [2].

Rather than this bottom-up approach from microscale models, the meteorological community has adopted a top-down approach using mesoscale models [3]. These models are driven by global data assimilation models that, by dynamic downscaling, can resolve the scales of motion of the atmosphere to spatial resolutions of the order of a few kilometers. Regional wind maps are the typical products of these methods, useful for initial spatial planning but not detailed enough for site assessment purposes.

Advances in high performance computing (HPC) enables numerical exploration of the terra-incognita that links mesoscale and microscale scales [4]. The overlapping of bottom-up and top-down approaches, using dynamic or statistical methods, is a very active field of research not only for the wind energy sector but also for the wider atmospheric science community [5].



## 2.0 Objectives and Strategy

The objective of this IEA Wind Task 31 is to develop a verification, validation, and uncertainty quantification (VV&UQ) framework that will support sustained improvement of wind farm models (opening figure). This continuous evaluation process requires the simulation of as many test cases as possible in order to gain confidence and credibility of the model results within the intended use of the model and its range of applicability [6].

A building-block approach will progressively validate the model by adding increasing levels of geometrical and physical complexity. This hierarchical process requires that the simulation and experimental data share the same or similar hypothesis in order to systematically analyze the results in a consistent way. Hence, a combination of theoretical, laboratory (wind tunnel), and field experiments are combined to validate the wind farm system by using a number of subsystem and unitary problems. Fit-to-purpose validation (error) metrics for each benchmark are defined in order to quantify model performance on a set of variables of interest (e.g., mean wind speed, turbulence intensity, etc.). The uncertainty quantification process will integrate these metrics in a probabilistic model considering the relevant range of wind climate and wind farm operating conditions and their associated uncertainty.

**Table 1. Countries and Organizations Participating in Task 31 During 2015**

| | Country/Sponsor | Organization(s) |
|---|---|---|
| 1 | Denmark | DTU Wind Energy; DONG Energy; VESTAS Wind & Site Competence Centre; EMD International A/S |
| 2 | Finland | VTT - Technical Research Centre of Finland |
| 3 | France | EDF R&D; IFP Energies Nouvelles; Université du Havre; Meteodyn; Université d'Orléans |
| 4 | Germany | ForWind - Oldenburg University; DEWI; SUZLON; German Aerospace Center |
| 5 | Japan | University of Tokyo; Wind Energy Institute of Tokyo |
| 6 | Netherlands | Energy Research Centre of the Netherlands; Technical University of Delft |
| 7 | Spain | National Renewable Energy Centre of Spain; EDP Renovaveis |
| 8 | Sweden | Upsala University |
| 9 | Switzerland | École Polytechnique Fédérale de Lausanne; Swiss Federal Institute of Technology |
| 10 | United States | National Renewable Energy Laboratory; Sandia National Laboratories; Indiana University; University of Wyoming; National Center for Atmospheric Research; Lawrence Livermore National Laboratory; Los Alamos National Laboratory; University of Minnesota |

# 11 Task 31

An overarching goal of Task 31 is to create a forum for international cooperation in flow modeling for wind energy where project participants can leverage results and data from parallel projects related to the topic. In particular, there are two large research initiatives that will sustain the work in Task 31: the New European Wind Atlas (NEWA) project and United States Department of Energy Atmosphere to Electrons (A2e) program. Both share common objectives (multi-scale modeling, experimental campaigns, VV&UQ, open-access to data) and will use Task 31 to reach out to the international community.

The working methodology (opening figure) is based on the benchmarking of different wind and wake modeling techniques in order to identify and quantify best practices for using these models under a range of conditions: both land-based and offshore, from flat to very complex terrain. Most of the work is organized around benchmark exercises on verification and validation test cases. In order to facilitate the management of these exercises, the www.windbench.net web platform is used, ruled by a model evaluation protocol which is the main deliverable of Task 31 [6].

## 3.0 Progress in 2015

The second phase of Task 31 kicked off in June 2015 and has 10 participating countries: Denmark, Finland, France, Germany, Japan, Netherlands, Spain, Sweden, Switzerland, and the United States. The Task, originally coordinated by National Renewable Energy Centre (CENER) and the National Renewable Energy Laboratory (NREL), has now added DTU to lead a work package on uncertainty quantification. A Topical Expert Meeting jointly organized with Task 11 Base Technology Information Exchange on uncertainty quantification for wind assessment was used to launch this new activity in the Task.

Initial activities have been focused on upgrading the windbench website to a new platform, identifying suitable cases for benchmarking of atmospheric boundary layer and wake models, as well as defining a roadmap for the implementation of uncertainty quantification in the model evaluation protocol (Figure 1). Initial benchmarks for atmospheric models deal with the atmospheric boundary layer over simple terrain. This is directly applicable to many situations offshore, where wake and uncertainty quantification benchmarks are initially focused.

Atmospheric models will be initially benchmarked to reproduce steady-state and transient conditions in flat terrain under a range of large-scale forcing and surface conditions. Test cases from NEWA and A2e are being considered around the simulation of idealized quasi-steady profiles, diurnal cycles, and canopy flows.

Two expressions of interest to access data from Alpha Ventus and Rødsand 2 wind farms have been submitted to the RAVE and OWA consortiums. The objective is to look for validation cases to study both the incoming flow and the turbine or wind farm response as an integrated system. To this end, collaborations with Task 30 Offshore Code Comparison Collaboration Continued with Correlation (OC5) and Task 32 LIDAR: Lidar Systems for Wind Energy Deployment has been established in order to enable interdisciplinary cooperation.

## 4.0 Plans for 2016 and Beyond

In 2016, the work is directed to the implementation of new validation cases for benchmarking. Often the cases have been studied as part of a national or European project and are brought to Task 31 to extend the work to a larger variety of models. For example, the Texas Tech University 200-m met tower used to study the inflow conditions to the scaled wind farm SWiFT facility, hosted by Sandia National Laboratories. Experiments with three Vestas V27-300-kW wind turbines will be conducted in 2016 to study wake generation, propagation, and interaction processes at different yaw misalignment conditions.

The NEWA project in Europe will also leverage validation cases for flow over a heterogeneous forest canopy in Sweden (Ryningsnäs) to study mean profiles in neutral and stable conditions, as well as a diurnal cycle leading to a nocturnal low-level jet based on the GABLS3 benchmark originally conducted by the boundary-layer meteorology community. Validation cases from Alpha Ventus and Rødsand 2 experiments will be selected for benchmarking in the second half of the year.

The extension of the model evaluation protocol is also an important objective in 2016. The scope of the Task is extended to mesoscale and near-wake models, always with a focus on wind resource assessment and wind farm design applications. The evaluation framework will be extended to include uncertainty quantification. The resulting VV&UQ framework will include a planning instrument for experiments and model validation based on the Phenomena Identification and Ranking Table (PIRT), originally developed by Sandia and other United States laboratories [7]. This instrument relates the modeling requirements of the target application with the validation activities. By experts' consensus, it prioritizes experimental and validation tasks following a building-block approach of increasing levels of complexity to progressively and systematically build confidence in the models.

The PIRT process is already established in the A2e program focusing on atmospheric and wake models. It has also been adopted in the NEWA project for mesoscale to microscale atmospheric flow models. Task 31Wakebench will integrate these two initiatives to come up with a coordinated plan for VV&UQ based on a unified PIRT.

**References:**

Opening photo: Graphic of Workflow of the VV&UQ framework as defined in the Wakebench Model Evaluation Protocol (Photo credit: Sanz Rodrigo, J. and Moriarty, P., 2015)

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[7] Hills, R.G., Maniac,i D.C., Naughton, J.W. (2015)*V&V Framework*. Sandia Report SAND2015-7455, September 2015

Author: Javier Sanz Rodrigo and Ivan Moya, National Renewable Energy Centre (CENER), Spain, Patrick Moriarty, National Renewable Energy Laboratory (NREL), United States, and Pierre-Elouan Réthoré, DTU Department of Wind Energy, National Laboratory for Sustainable Energy, Denmark.

# 12 Task 32

## LIDAR: Wind Lidar Systems for Wind Energy Deployment

## 1.0 Introduction

**Lidar is a sensing technology that uses laser light that is backscattered from aerosols in the atmosphere to remotely measure wind speed in the line of sight. This information can be used to estimate wind characteristics such as wind speed, direction, and turbulence.**

**IEA Wind Task 32 addresses the fast development of wind lidar technologies and their applications in wind energy power systems. In the first three-year phase which concluded in 2015, participants from the industrial and academic community worked jointly to assess the state-of-the-art of lidar applications for wind energy. The task aims to produce results in the form of experimentally-tested recommended practices and other reports for wind lidar measurements based on the experiences of academic and industry participants. In the second phase, beginning in 2016, the originally broad scope of the task has been narrowed to focus on identifying barriers to the use of lidar technology in the wind energy field.**

**Overall, 48 institutions from 17 countries participated in the activities of Task 32 Phase 1, including research centers, universities, wind measurement companies, and lidar and wind turbine manufacturers (Table 1).**

## 2.0 Objectives and Strategy

IEA Wind Task 32 aims to establish a vital community and to provide an international open platform for industrial and academic partners to exchange new ideas, experiences, and measurement techniques for lidar in wind energy. The task also aims to publish experimentally-tested recommended practices and other reports for wind lidar measurements based on the joint experience of the participants.

IEA Wind developed and approved in 2012 the *IEA Wind Recommended Practices 15: Ground-Based Vertically-Profiling Remote Sensing for Wind Resource Assessment* (http://ieawind.org/task_11/recomend_pract.html) under Task 11 Base Technology Information Exchange. This report set the stage for additional research on remote sensing. Further understanding gained in Task 32 will be collected and either summarized in an addendum to the Recommended Practice or included in a second edition of that document.

State-of-the-art and technical reports will provide guidance for an accurate calibration of ground- and nacelle-based lidar. They will include information for better understanding of lidar-measured wind and turbulence and give indications about the application of lidar in flat terrain and complex flow conditions. Some reports will also be dedicated to the application of lidar for wind turbines, such as the application of rotor-equivalent wind speed or nacelle-based lidar for power curve assessment.

In Phase 1, general meetings were organized at least once per year. The scientific and technological content of Task 32 was gathered in working groups split up into three subtasks (Table 2). For-Wind–University of Oldenburg acted as Operating Agent or manager of the task; coordination of the three subtasks was delegated to the partners assisting the Operating Agent: Technical University of Denmark (DTU) Wind Energy, the U.S. National Renewable Energy Laboratory (NREL), and the German Stuttgart Wind Energy (SWE)–University of Stuttgart. The organization strategy of the task has been changed for Phase 2, see Section 4.0.

## 3.0 Progress in 2015

In 2015 participants finalized the first phase of the task and completed the several reports. In particular, *Estimating Turbulence Statistics and Parameters from Ground- and Nacelle-Based Lidar Measurements*, an IEA Wind Experts Group Study report about turbulence measurements with lidar was published in 2015 [1]. This comprehensive document describes the technologies available for both ground- and nacelle-based lidar measurements and presents the mathematical tools needed for the corresponding data (Figure 1). It also provides results from exemplary measurement campaigns where the techniques and procedures explained in the preceding chapters are applied.

**Table 1. Countries and Organizations Participating in Task 32 from 2012 to 2015**

| | Country/Sponsor | Organization(s) | Status |
|---|---|---|---|
| 1 | Canada | AXYS Technologies; Technocenter Eolien | Joined 2013 |
| 2 | CWEA | Beijing New Energy Technology; China Renewable Energy Engineering Institute; Chinese Wind Energy Association; Goldwind, Science & Technology | Joined 2014 |
| 3 | Denmark | DONG Energy; DTU Wind Energy; Vestas; Windar | Joined 2012 |
| 4 | France | Avent Lidar; Epsiline; Institut Français du Pétrole Energies Nouvelles; Leosphere | Joined 2015 |
| 5 | Germany | Adwen; Deutsche WindGuard; Deutsches Windenergie-Institut; DNV-GL; ForWind – University of Oldenburg; Fraunhofer IWES; GWU-Umwelttechnik; Senvion SE; Stuttgart Wind Energy – University of Stuttgart | Joined 2012 |
| 6 | Japan | ITOCHU Techno-Solutions; Mitsubishi Electric | Joined 2012 |
| 7 | Netherlands | Energy Research Centre of the Netherlands | Joined 2014 |
| 8 | Norway | Norwegian Centre for Offshore Wind Energy; University of Bergen | Joined 2013 |
| 9 | UK | Carbon Trust; Frazer Nash; National Engineering Laboratory; Natural Power; Offshore Renewable Energy Catapult LiDAR; Renewable Energy Systems; Sgurr Energy; Scottish and Southern Energy; Zephir | Joined 2014 |
| 10 | United States | AWS Truepower; Cooperative Institute for Research in Environmental Science; National Center for Atmospheric Research; National Oceanic and Atmospheric Administration – Earth System Research Laboratory; National Renewable Energy Laboratory; Pacific Northwest National Laboratory; University of Colorado | Joined 2012 |
| 11 | Austria | Energiewerkstatt Verein | Interested |
| 12 | Belgium | 3E | Interested |
| 13 | Israel | Pentalum Technologies | Interested |
| 14 | Sweden | WindVector AB | Interested |
| 15 | Switzerland | Meteotest | Interested |

**Table 2. Organization in IEA Wind Task 32 Phase 1**

| IEA Wind Task 32 Wind Lidar Systems for Wind Energy Deployment M. Kühn (ForWind) | | |
|---|---|---|
| Subtask I:<br>Calibration and Classification of Lidar Devices<br>M. Courtney (DTU) | Subtask II:<br>Procedures for Site Assessment<br>A. Clifton (NREL) | Subtask III:-<br>Procedures for Turbine Assessment<br>A. Rettenmeier (SWE) |

In the work package that investigated the state-of-the-art for using lidar in complex flow situations, results showed that both a common definition of complex flow and a framework for classifying different measurements were lacking—this led to challenges in understanding the current state of the technology. In response, participants created a definition of complex flow applicable to lidar and defined several use cases for lidar in complex flow, enabling experiences from different counties and applications to be shared and compared. Based on the collected experience, several potential recommended practices were identified (Figure 2). The work package's results were summarized in

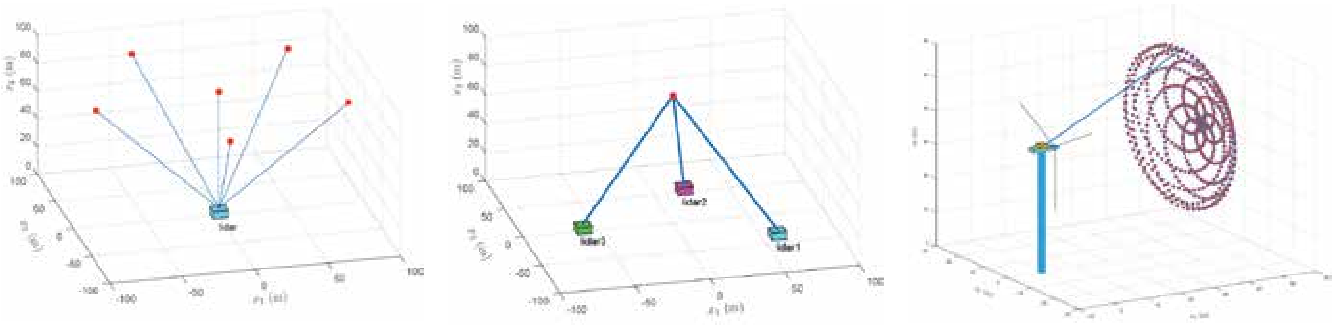

Figure 1. Possible scanning configurations for turbulence measurements: six beam configuration (left), intersecting beams (center), and nacelle-based lidar [1]

a 2015 technical report *Remote Sensing of Complex Flows by Doppler Wind Lidar: Issues and Preliminary Recommendations* [2].

Another activity was a blind comparison exercise. The objective was to reconstruct the three-dimensional wind components from raw lidar data and calculate values that were as close as possible to the measurements from three sonic anemometers on a meteorological mast. Only the coordinates of the measurement points and the ten-minute average values of the line-of-sight wind speeds were provided. The evaluation criterion was the absolute mean error over the three wind components from the three sonic anemometers. Five researchers from three organizations participated in the exercise. The three best results were very close with higher accuracy than the baseline error, showing that current methodologies used for wind field reconstruction can be improved.

Additionally, leaders of the Phase 1work packages and other participants refined the task organization, meeting, and communication strategies for the Phase 2 of the task.

## 4.0 Plans for 2016 and Beyond

Task 32 Phase 2 aims to identify and mitigate barriers to the use of lidar for the following wind energy applications: site assessment, power performance, loads and control, and complex flow detection. The four application areas are addressed individually because each is at different technology readiness levels. Figure 3 shows their relative positions regarding barriers to using lidar between implementation issues and open research questions.

To pursue this objective, an advisory board with members from academia and industry is designated to support the Operating Agent to define and organize technical workshops on specific topics within the application areas. Task 32 will have one workshop per year for each of the application areas, each focusing on a specific barrier such as those detailed in Table 3.

Beyond the specific objectives of each application area, Task 32 Phase 2 continues to provide an international open platform for regular and continuous exchange by organizing general meetings and distributing a quarterly newsletter. This allows participants to interconnect and leverage experience from several research projects and to identify areas for further research and development, as well as needs for standardization.

Further, the task plans to revise the *IEA Wind Recommended Practices 15: Ground-Based Vertically-Profiling Remote Sensing for Wind Resource Assessment* and to compile an IEA Wind Recommended Practices on Floating Lidar Systems based on the work done in Phase 1.

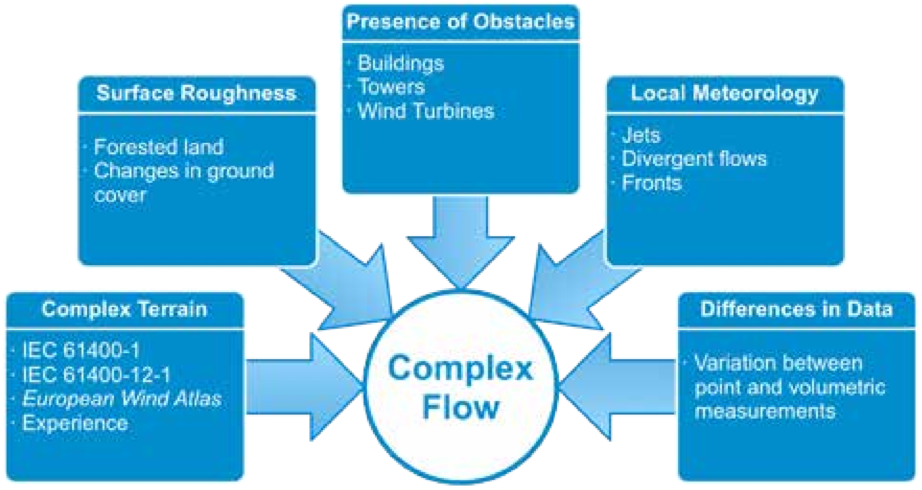

Figure 2. Indicators of complex flow that may be important for comparisons of lidar and point measurements [2]

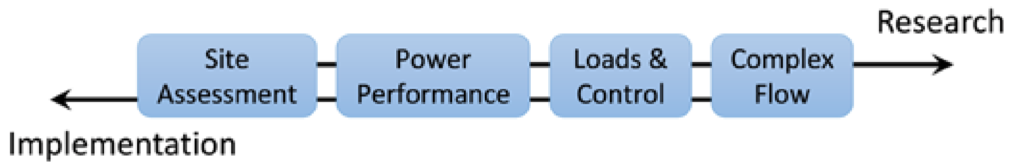

Figure 3. The four main application areas in Phase 2 of IEA Wind Task 32

**Table 3. Specific Topics for Application Areas in Task 32 Phase 2**

| Site Assessment | Power Performance | Loads and Control | Complex Flow |
|---|---|---|---|
| • Revise IEA Wind RP15<br>• Improve accuracy and availability of lidar systems<br>• Identify gaps and requirements to increase the maturity of Floating Lidar Systems | • Identify and address gaps in standards<br>• Address obstacles to widespread adoption<br>• Extend ground-based lidars standards to nacelle/spinner-based applications | • Identify benefits for the cost of wind energy<br>• Improve lidar for control applications<br>• Apply lidar in the certification of wind turbines | • Develop metrics to compare lidar measurements and wind simulations<br>• Identify the limitations of lidar systems in relation to the need for measurements in complex flow |

**References:**

Opening photo: Nacelle-based lidars installed on a wind turbine prototype in northern Germany. The panorama view includes the two lidars which were placed in the front and in the rear of the nacelle, respectively. (Credit: Stephan Voss from ForWind—University of Oldenburg)

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Authors: David Schlipf and Ines Würth, SWE—University of Stuttgart, Germany; Martin Kühn and Davide Trabucchi, ForWind—University of Oldenburg, Germany; and Andrew Clifton, National Renewable Energy Laboratory, the United States.

# 13 Task 33

## Reliability Data: Standardizing Data Collection for Wind Turbine Reliability and Operation & Maintenance Analyses

## 1.0 Introduction

**In general the objective of IEA Wind Task 33 is to support reliability improvement and the optimization of operation and maintenance (O&M) procedures of wind turbines through analyses of reliability data.**

**Task 33 explores the initiatives of data and failure statistics collection in the wind energy sector of the participating countries. The group prepared a survey about which data should be collected and which analyses can be performed. Another goal of the survey was to identify existing guidelines and experience, as well as gaps and barriers for utilizing reliability data. Using this information, the task team will identify typical indicators and analyses and recommendations for which reliability and other data should be collected. Based on these results, the group will prepare and publish a summary of the data to record, how to transfer it into databases, and how to structure databases for storing and analyzing.**

**In the end, an IEA Wind Recommended Practices will provide the final results to the wind industry. The document will explain the different possibilities for utilizing reliability and maintenance data and it will give guidelines on how to proceed for different individual scopes.**

**The task started with representatives from nine countries and in the meantime welcomed two more. Table 1 shows the current team.**

## 2.0 Objectives and Strategy

The drivers for IEA Wind Task 33 are:

- Extensive national research projects dedicated to reliability analyses on wind turbine failures have been performed during the last years in Denmark, Finland, Germany, Netherlands, Sweden, the United Kingdom, and the United States. However, a consolidated multi-lateral and international exchange has, to date, only partially taken place.
- Several working groups on appropriate standards for O&M of wind power plants have been launched at national levels for land-based wind energy applications, e.g., joint activities on standardizing O&M measures, documentation, and data structure.
- Increasing future demands on reliability and profitability of wind energy, especially offshore, require the optimization of wind-turbine maintenance for which appropriate data management and sophisticated decision-support tools are prerequisites.

However, up to now there are no comprehensive guidelines or standards to refer to, meaning results of existing initiatives are nearly incomparable and data cannot be compiled and analyzed commonly. Thus, the competencies gained in IEA Wind Task 33 will be collected and summarized in an IEA Wind Recommended Practices for Reliability Data.

Owners and operators strive to optimize maintenance efforts rather than availability and life cycle cost. Thus, their needs for decision support by key performance indicators and other information from historical O&M data is the basis for identifying the right data sets to record. In summary, the objectives of Task 33 include identifying operators' demands, selecting the most appropriate statistical methods for providing key figures, and providing recommendations for which data to collect.

Task 33 began by exploring initiatives of data collection and failure statistics in the wind energy sector in participating countries. The results showed there is an extensive interest in confident reliability data and a variety of databases already exist. Of these wind-related initiatives, thirteen gather reliability data and feed it into databases. These databases were investigated and compared to each other. Only five databases contain cost information.

Nearly all databases use different systems to structure wind turbines, different component designations, and different failure descriptions. International standards concerning terminology and communication have not been considered and are different in terms of data gathered and continuity of samples, structure and format of data, duration period, and wind turbine types considered. Important data on events and cost are missing in most cases. This means that data on events and cost cannot be compared to each other.

These findings and additional feedback from industry representatives demonstrate that an IEA Wind Recommended Practices on data collection and data analyses would be very welcome.

## 3.0 Progress in 2015

The Task 33 team compiled a joint document from the results of three working groups, which provide background information for further work and the future Recommended Practices. It describes:

- The motivation for using reliability data in the field of maintenance,
- Typical maintenance strategies and maintenance tasks,
- Statistical analyses, their opportunities and limitations,
- Methods for assessing failure probabilities or identifying critical components,
- Data groups and taxonomies for component designations and failure categorization.

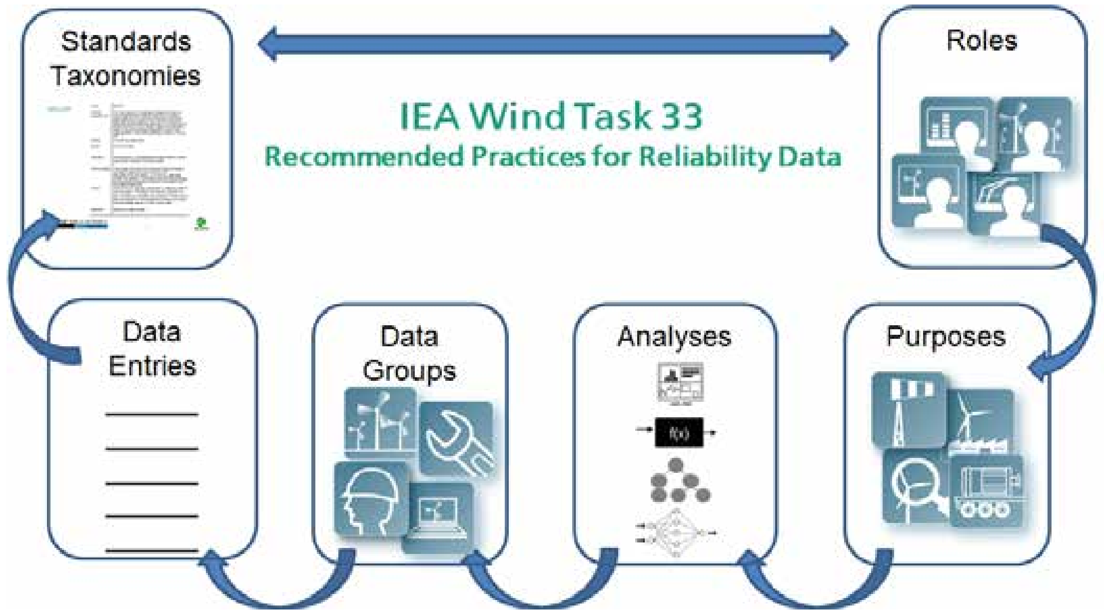


Figure 1. Determining data needed and appropriated taxonomies from roles and approaches

The next steps are to identify the most important analyses, commonly derive suggestions from the written document, and discuss intermediate outcomes with industry representatives.

In September 2015, an industry workshop was held consisting of the three sessions: Industry Perspective; Research Perspective; Moderated Discussions. Forty participants from 11 countries discussed the necessity of an international guideline, as well as the most important requests from industry. Participants came to following conclusions:

- Maintenance of wind turbines and maintenance documentation needs improvement,
- Current data availability and data quality are low,
- A standard/guideline is needed as a how-to and as a reference in contracts.

The main requests to be included in the IEA Wind Recommended Practices are sudden events, regular services, and degradation of components; live time extension; and harmonization of status codes and alarm logs, as well as communication issues. One important additional request was to "make it short and easy to read!" The Task 33 team decided to consider some but not all requests. The harmonization of status codes and alarm logs tasks are too big to be addressed within the current phase of the task. The ongoing work focusses on identifying roles within O&M of wind turbines and their needs when utilizing O&M data, on finding appropriate analyses to fulfil these needs, and on determining the needed data inputs (Figure 1).

## 4.0 Plans for 2016 and Beyond

The current phase of IEA Wind Task 33 will expire in September 2016. Thus, the IEA Wind Task 33 team strives to complete the Recommended Practices, including adding bilateral interviews with industry representatives. Two additional in-person meetings are planned for spring and late summer. The final meeting will be combined with another industry workshop as a side event to the European Wind Energy Conference in Hamburg. Task 33 intends to leverage this opportunity to present their outcomes to a large group of experts.

**References:**

Authors: Berthold Hahn and Stefan Faulstich, Fraunhofer Institute for Wind Energy and Energy Systems Technology, Kassel, Germany.

**Table 1. Countries and Organizations Participating in Task 33 During 2015**

| | Country/ Sponsor | Organization |
|---|---|---|
| 1 | CWEA | Chinese Wind Energy Association (CWEA); Goldwind |
| 2 | Denmark | DTU / University Aalborg |
| 3 | Finland | VTT Technical Research Centre of Finland |
| 4 | France | Maia Eolis |
| 5 | Germany | Fraunhofer IWES |
| 6 | Ireland | ServusNet |
| 7 | Netherlands | Delft University of Technology, Energy Research Centre of the Netherlands (ECN) |
| 8 | Norway | SINTEF Foundation for Scientific and Industrial Research; NTNU University Trondheim |
| 9 | Sweden | Vattenfall; Chalmers University Gothenburg |
| 10 | UK | ORE Catapult |
| 11 | United States | Sandia National Laboratories |

**re•li´•a•bil´•i•ty (ri, līə 'bilətē) *n.***
a person or thing with trustworthy qualities. Task 33 · Reliability Data

# 14 Task 34

## Working Together to Resolve Environmental Effects of Wind Energy (WREN)

## 1.0 Introduction

**The objective of Task 34, Working Together to Resolve Environmental Effects of Wind Energy (WREN), is to address challenges pertaining to the environmental effects of wind energy on the wide-scale deployment of both offshore and land-based wind energy projects. WREN was formed to serve as the leading international forum for facilitating deployment of wind energy technology around the globe through a better understanding of environmental issues and demonstrated solutions for those challenges. During 2015, membership in WREN expanded from five to ten countries (Table 1). Representatives from non-member countries have also contributed to task activities.**

## 2.0 Objectives and Strategy

The primary objective of WREN is to facilitate international collaboration to advance global understanding of the environmental effects of offshore and land-based wind energy development. The strategy to accomplish this objective is to create a shared global knowledge base on research, monitoring, and management of the environmental effects of wind energy development.

Task participants contribute to the advancement of the knowledge base by providing what is known about the impacts of wind energy technology on wildlife. WREN Hub—a publicly available, online, centralized knowledge management system—has been developed to facilitate easy access to existing literature and relevant information on the effects of wind development on wildlife and habitats.

WREN Hub also contains scientifically robust information that is available to all interested stakeholders, including the research community, wind development community, environmental community, government regulatory organizations, and others. White papers are under development, focusing on and advancing the state of understanding about central issues of global concern within the wind/wildlife community. A webinar series and other direct outreach approaches are also used to regularly disseminate information on relevant WREN topics.

## 3.0 Progress in 2015

Throughout the year, WREN members worked on three key activities: 1) WREN Hub, 2) white papers, and 3) information dissemination, including a webinar series. Progress was made on all task activities in 2015. To assist in the coordination of these activities, three virtual meetings and two in-person meetings were conducted during 2015. The in-person meetings, organized by WREN members, fostered an international forum for exchange of knowledge and experiences and provided an opportunity to discuss specific activities in greater depth.

The Berlin Institute of Technology hosted a meeting in Berlin, Germany, in conjunction with the Conference on Wind Energy and Wildlife Impacts (CWW) in March 2015. Ten representatives from seven member countries attended this meeting and several made presentations about WREN at CWW.

In the autumn of 2015, WREN members met in Bern, Switzerland. The 21–22 October meeting was organized by nateco AG and hosted by the Swiss Federal Office of Energy. Thirteen participants attended the meeting in person and another three participated via phone. In total, seven countries had representation at the meeting. A description of progress on specific 2015 task activities is provided below.

### 3.1 Progress on developing the WREN Hub

The purpose of the WREN Hub is threefold: 1) to advance international understanding of, and disseminate information about, the environmental effects of offshore and land-based wind energy, 2) to facilitate international collaboration on common issues of concern, and 3) to create an international community with access to relevant information. WREN Hub is a collaboration supported by an information technology platform. It is designed to:

- Act as a commons or gathering place for those interested in the environmental effects of wind energy development,
- Serve as an online platform for information sharing,
- Provide tools for communication and collaboration among WREN member nations,
- Deliver expert content through seminars and workshops, and
- Act as a managed clearinghouse, events calendar, and bulletin board for key events and news items. Figure 1 provides a visual representation of the WREN Hub.

During 2015, development of WREN Hub was completed. It is hosted on the *Tethys* platform developed by the U.S. Department of Energy's Pacific Northwest National Laboratory (http://tethys.pnnl.gov). The *Tethys* platform, which is a knowledge base for marine and wind energy environmental issues, was enhanced to accommodate the needs of WREN Hub during 2015.

The hub is populated with documents and information pertaining to both land-based and offshore wind energy. WREN Hub is updated regularly to include recent publications and notifications of upcoming events (such as meetings, conferences, and webinars) and currently hosts more than 2,600 papers and reports, of which more than 2,100 are pertinent to wind and wildlife. During 2015, 1,366 documents were added to *Tethys*, with 814 related to land-based wind and 274 related to offshore wind.

All material on WREN Hub is publicly available, with the exception of a members-only page where in-progress product development is accessible. Once these products are finalized, they will be migrated to the public access side of WREN Hub. A link to WREN Hub can be found on the IEA Wind Task 34 website (www.ieawind.org/task_34.html) to ensure all interested parties have easy access to the hub. WREN Hub can also be accessed directly from the *Tethys* homepage (http://tethys.pnnl.gov).

Use of WREN Hub increased as its availability has become better known. In 2015, there were 1,577 views of the WREN Hub page, with 710 views of the WREN members-only page. Users also viewed the recorded WREN webinars during 2015, as follows:

- WREN Webinar 1: 396 views
- WREN Webinar 2: 334 views
- WREN Webinar 3: 2,725 views
- WREN Webinar 4: 1,372 views
- WREN Webinar 5: 814 views.

### 3.2 Progress on developing white papers

In 2015, WREN members made progress on three white papers. As background, once WREN members have agreed on a white paper topic, they develop the white paper using the following approach: 1) identify a core writing team, 2) develop the paper outline and annotated bibliography, 3) draft the paper, 4) conduct workshops to discuss the draft, 5) use input from workshops to inform development of the final draft document, 6) review, and 7) publish. Publication

**Table 1. Countries and Organizations Participating in Task 34 During 2015**

| | Country/Sponsor | Organization(s) |
|---|---|---|
| 1 | France* | Electricity of France (EDF R&D) |
| 2 | Germany | Berlin Institute of Technology |
| 3 | Ireland | BirdWatch Ireland |
| 4 | Netherlands | Rijkswaterstaat - Department of Water Quality |
| 5 | Norway | Norwegian Institute for Nature Research |
| 6 | Spain* | Spanish Council for Scientific Research |
| 7 | Sweden | Swedish Energy Agency; Vindval |
| 8 | Switzerland | Federal Department of the Environment, Transport, Energy and Communication (DETEC); nateco AG |
| 9 | UK | Marine Scotland Science |
| 10 | United States | National Renewable Energy Laboratory;<br>Pacific Northwest National Laboratory;<br>U.S. Department of Energy |

*France and Spain became members of WREN in 2015; however, both countries were inactive during 2015. Portugal, although not a member of WREN, made contributions to WREN activities during the year.

# 14 Task 34

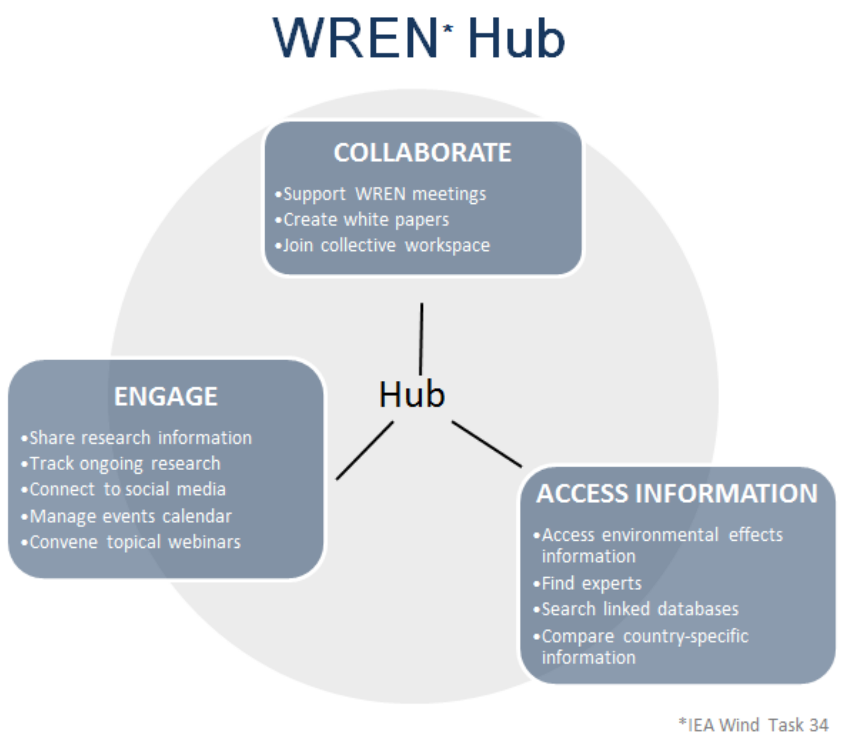


Figure 1. WREN Hub components

may be in the form of an IEA Wind Technical Report or may be via a peer-reviewed journal.

In 2015, members continued development of WREN's first white paper, with a working title of *Adaptive Management White Paper*. The paper will define adaptive management (AM) in the context of the United States Department of the Interior technical guide on Adaptive Management [1]. A preliminary draft was distributed to WREN members and discussed in detail during the October 2015 meeting in Switzerland. Publication of this first white paper is anticipated in mid-2016 as an IEA Wind Technical Report. Based on input received, the document will be expanded to include the following:

- An examination of the use of AM for wind energy internationally, including the various policies and management principles,
- Factors that have contributed to AM success stories and challenges,
- Case studies to illustrate uses of AM, including bird and bat conservation plans that do not necessarily refer directly to AM, and
- Discussions about the future use of AM for land-based and offshore wind development.

In 2015, WREN members made progress on the development of a second white paper, with a working title of *Considerations for Upscaling Individual Effects of Wind Energy Development Towards Population-Level Impacts on Wildlife*. The purpose of this paper is to provide an overview of how populations are to be defined, measured, and predicted and how to set thresholds for losses of wildlife that will potentially affect the underlying populations. A preliminary draft of this topical white paper was discussed during the October 2015 in-person meeting in Switzerland. It is anticipated this paper will be submitted to a peer-reviewed journal in late 2016.

WREN members also began preliminary work on a third white paper (identified as Green versus Green) in 2015. This paper, with a working title of *Reconciling Argumentations For and Against the Sustainable Development of Wind Energy*, is intended to examine the mismatch in scale of the arguments used for and against wind energy development. Specifically, proponents of wind energy highlight the global benefits of reducing $CO_2$ emissions to mitigate climate change, while opponents voice concerns for the local costs of biodiversity and ecosystem services through landscape and seascape changes.

### 3.3 Progress on information dissemination

Three webinars were held in 2015. In April, the webinar presentation focused on *Understanding Avian Collison Rate Modeling and Application at the Population Level*. Mark Collier from Bureau Waardenburg in the Netherlands and Aonghais Cook from the British Trust for Ornithology in the United Kingdom provided a combined presentation.

A second webinar was held in August and focused on avian sensitivity mapping and wind energy. Julia Wilmott from Normandeau presented on the company's sensitivity index for birds to offshore wind, which featured information about how data collection methods affect inputs of modeled potential impacts to collision and displacement and how this affects the industry as a whole.

Roel May from Norwegian Institute for Nature Research (NINA) discussed NINA's Geographic Information System-based wind turbine micrositing tool for preconstruction assessments, which identifies sites that are attractive to migratory and soaring birds due to the spatial distribution of topography, landform orientation, and thermal and orographic updrafts. Sinéad Cummings, from BirdWatch Ireland, provided a summary of the recently completed Bird Sensitivity Mapping tool.

In December, a third webinar focused on wildlife monitoring. Kate Williams from Biodiversity Research Institute provided a summary of the Mid-Atlantic Baseline Studies Project and Henrik Skov from DHI Group described the Thermal-Visual-Animation-Detection-System and development of multi-sensor detection systems. The webinars were recorded and posted to the WREN Hub (tethys.pnnl.gov/environmental-webinars?content=wind).

Throughout 2015, WREN members continued to disseminate information about WREN through various mechanisms. In March, WREN members participated in the CWW in Berlin, Germany. In addition to providing a panel presentation and poster presentation, WREN convened a workshop session, engaging more than 40 people from 15 countries in a discussion of how adaptive management is used in the context of wind energy development.

## 4.0 Plans for 2016 and Beyond

WREN members will continue to work on the activities identified in the work package (see Task 34 Work Plan on ieawind.org for details). These activities will include: 1) the expansion of WREN Hub to include more literature, use of social media channels available within the hub, and the provision of information on upcoming meetings, conferences, webinars, and other activities of interest to WREN members; 2) continued work on white papers, publishing papers as they are completed; and 3) continued active dissemination of information, through the WREN Hub, webinars, social media, and participation in relevant conferences.

WREN members will engage in planned activities and product development using a variety of communication strategies, including virtual meetings, conference calls, webinars, WREN Hub, and other communication formats as appropriate. The success of WREN is dependent on all participating countries actively engaging in the various activities. The United States has and will continue to support administrative and operating costs of the Operating Agent. No membership fees will be required to participate in WREN; however, each participating country must submit a formal commitment letter to IEA Wind and agree to provide in-kind contributions to cover staff time to contribute to the development of products and travel costs to attend in-person meetings (at least two per year to be held in the spring and autumn). In addition to the current member countries, representatives from several other countries who have expressed interest in participating in WREN will be encouraged to submit commitment letters.

Two in-person meetings are planned for 2016. The first will be held in Dublin, Ireland, on 4–5 April 2016. During this meeting, member countries will continue to work on all the work package activities, including the completion of the first white paper focused on adaptive management, continued work on the second white paper on the individual effects to population impacts, and work on the third white paper, Green versus Green. The second meeting will be held in the United States, in Broomfield, Colorado, on 28 November. It will be co-located with the National Wind Coordinating Collaborative Wind Wildlife Research Meeting XI, where several WREN members anticipate giving oral presentations and providing poster presentations. Topic-specific workshops will be scheduled, if needed, to expedite the development of the white papers.

A preliminary proposal for extension was presented to the IEA Wind 77th Executive Committee meeting 9–12 May 2016, in Lisbon, Portugal. The extension reprioritizes the overall WREN work effort, focusing on the development and publication of additional white papers, continued enhancements of and additional references in WREN Hub, and expanded outreach and information dissemination activities. The final proposal for extension will be submitted for approval during the 78th IEA Wind Executive Committee meeting in November 2016 in Brussels, Belgium.

**References:**

Opening photo: At the Smøla wind farm, white-tailed eagles and willow ptarmigans commonly collide with wind turbines. Concerns about their collision rates triggered research testing the efficacy of various mitigation measures, including painting one of three rotor blades black at four turbines to alert white-tailed eagles and reduce collision risk. Similarly, up to 10 tower bases (0-10 meters) were painted black with the aim to raise the horizon to reduce collision risk in willow ptarmigan (which collide with the actual tower). Results from this research are expected in the coming years. (Photo: Roel May)

[1] www.usgs.gov/sdc/doc/DOI-%20Adaptive%20ManagementTechGuide.pdf

Author: Karin Sinclair, National Renewable Energy Laboratory (NREL), United States.

# 15 Task 35

### Full-Size, Ground Testing for Wind Turbines and Their Components

## 1.0 Introduction

**As wind energy continues to contribute an increasing portion of the electricity supply, it is crucial that design and testing standards for wind turbine generators keep pace with the development of the technology. The standards need to reflect requirements for improving reliability at low costs. Reducing the downtime and development costs of wind turbine generators ensures that wind energy remains competitive in the global electricity marketplace.**

**Although full-scale prototype turbine field testing is a common technique employed in the development of new products, it is expensive, time-consuming, and suffers from the predictability of site-specific load cases. As an alternative, ground-based test benches offer the opportunity to evaluate wind turbine components under reproducible, accelerated life conditions and may become an important tool for development and certification of new wind turbine generators.**

## 2.0 Objectives and Strategy

IEA Wind Task 35 intends to address the emerging demand for reliable and cost-effective ground testing. The use of full-scale ground test facilities for validating wind turbine designs has become an attractive option to the component manufactures, original equipment manufacturers (OEM), and owner/operators [1, 2]. The challenge is to exploit the potential of the testing facilities around the world and combine individual test methods into a uniform testing approach.

The goal of Task 35 is to formulate recommendations for ground-based test procedures for blades and nacelles and to standardize the procedures across the test facilities around the world. Depending on the recommended configuration, test rigs should be capable of performing the same standardized test with equivalent results at the same confidence level. As a long-term goal, the standardized test procedures support the following objectives:

- Advancement of certification processes,
- Improvement of the quality and reliability of nacelles and blades,
- Reduction of wind turbine design and development time, and
- Evaluation of in-field performance and possible failure modes of blade and drivetrain components.

Eventually, the use of test facilities for blades and nacelles should become a reliable alternative or complement to field tests for certification and design validation.

## 3.0 Progress in 2015

### 3.1 Subtask nacelle

3.1.1 Influences of abstraction

It is challenging to mimic the missing subsystems (e.g., rotor, tower, real grid, and environment) when performing nacelle test procedures. However, it is crucial for the fidelity and development of ground test procedures to consider the influence of abstractions that are made when emulating realistic field conditions for wind turbine nacelles mounted on a test rig in a laboratory (see Figure 1).

The magnitude and significance of abstraction effects on nacelle test results can vary due to specific test configuration and test rig setups. For example, the impact of test rig heat loads or humidity can be relevant or not, depending on the individual test purpose. However, there are few general effects that are common across the test facilities and require particular consideration. The experts of Task 35 nacelle subtask have created an overview of 29 major and minor abstractions including the description of the effects, the influence on test result, and the relevance for testing, as well as compensation possibilities, either physical or calculative. The following superordinate abstraction influences have significant impact on many test procedures.

The rotational inertia and the stiffness of the coupled drivetrains of test rig and nacelle have significant effects on local loads and the dynamic torsional behavior because of the missing rotor. Each individual property of the device under test (including the drivetrain stiffness, the rotor inertia, and aerodynamic transfer function) needs to be addressed in the torque load simulation. Furthermore, specific test controller adjustments are necessary to ensure adequate damping of false eigenfrequencies, natural resonant frequencies of the system. Independent of the form of the device under test, a rigid drivetrain, and sufficient dynamics of the test rig prime mover is recommended.

Nacelles on top of a 100-m tower can move 2 m back and forth, up to 0.2 Hz. Moreover, the tower at realistic in-field conditions bends and twists, which has a dampening effect on wind loads. In the test facility the device under test is fixed on a stiff foundation. For higher accuracy required for sensitive measurements (e.g., torque sensitive measurements at gear wheels) an individual adjustment using the wind load calculation model can be useful to compensate for the tower stiffness and movement. The subtask participants concluded that the device under test should be as stiff as possible due to the limited displacement of the load application actuators. The reaction forces of inertia on the system components due to the tower movement cannot be emulated on the test rig. These forces however are minor compared to the main loads.

On the electrical side, the grid connection simulation is limited to the performance (dynamic, accuracy, and power level) of the grid emulation hardware and power electronics. Depending on the test purpose, the simulation of the wind farm power level and grid strength requires adequate performance capabilities of the grid emulator (e.g., 100-MW wind farm transformer and 20 times of nominal power required for the grid).

Besides the power level, deviant response times, as well as harmonics up to 1 kHz in the emulation hardware interface causes accuracy losses. With transient effects of 1ms expected, the grid emulation controller needs to react two to three times faster than the operation cycle of the power electronic hardware. Although national grid codes requirements are increasing, it is still estimated that up to 80% of electrical certifications can be done at ground test facilities.

After evaluating these influences, the nacelle subtask concluded that the abstractions mentioned here can be compensated for current testing purposes. Compensation techniques are either physical (via adequate hardware) or calculative (via simulation models). The test results are expected to be comparable and transferable to in-field conditions. Moreover, the controlled environment of the test rig offers the potential to increase the fidelity and

**Table 1. Countries and Organizations Participating in Task 35 During 2015**

| | Country/ Sponsor | Organization(s) |
|---|---|---|
| 1 | CWEA | Goldwind Science & Technology Co., Ltd.; Institute of Electrical Engineering; Chinese Academy of Sciences; Shanghai Electric Wind Energy Co., Ltd.; China General Certification Center; Zhejiang Windey Co., Ltd. |
| 2 | Denmark | Technical University of Denmark (DTU)—Wind Energy; Lindoe Offshore Renewables Center (LORC); Vestas Wind Systems A/S; LM Wind Power A/S; R&D A/S; Blade Test Center A/S |
| 3 | Germany | Center for Wind Power Drives (CWD)—RWTH Aachen University;<br>Fraunhofer Institute for Wind Energy and Energy System Technology (IWES); Senvion GmbH; GE Energy Power Conversion GmbH;MTS Systems GmbH; Windtest Grevenbroich GmbH; HBM- Hottinger Baldwin Messtechnik GmbH; Tüv Rheinland AG; Technical University of Berlin; Siemens AG (Winergy) |
| 4 | UK | Offshore Renewable Energy Catapult; Lloyd's Register Group Services Ltd. |
| 5 | United States | National Renewable Energy Laboratory, National Wind Technology Center; Clemson University Wind Drivetrain Test Facility; McNiff Light Industry; Sandia National Laboratories; MTS Systems Corporation |
| **Countries Observing in Task** | | |
| | Observers | Organization(s) |
| 6 | Korea | Korea Institute of Materials Science (KIMS) |
| 7 | Netherlands | Knowledge Centre Wind turbine Materials and Constructions (WMC); We4Ce B.V. |
| 8 | Spain | National Renewable Energy Centre (CENER); Ingeniería y Dirección de Obras y Montaje (IDOM) |

# 15 Task 35

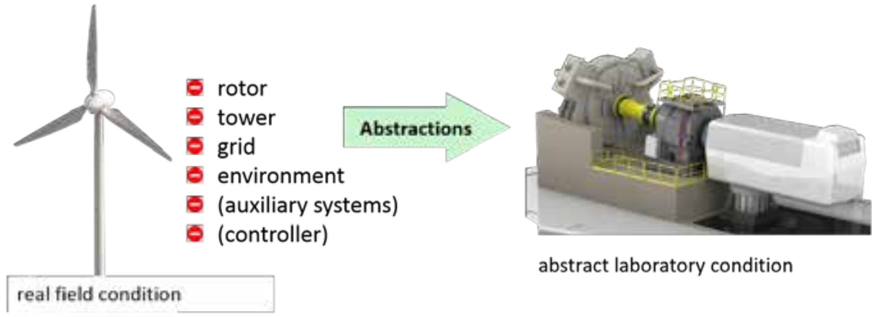


Figure 1. Influence of abstractions when emulating realistic field conditions for wind turbine nacelles are mounted on a test rig in a laboratory

understanding of the nacelle behavior in realistic conditions with the unique capability of reproducible loading.

### 3.1.2 Load cases

In late 2015, the nacelle subtask started to develop recommendations for load cases or design validation tests. The focuses for the first phase were robustness tests and controller optimization tests because these are currently the most relevant tests requested by customers. One of the major precepts is that the test load cases will be universally applicable, which means they must be independent from the device type under test, power level, region, or country.

The nacelle subtask selected the International Electrotechnical Commission (IEC) framework for test load cases, similar to the design load cases from the IEC 61400 standard. They will also refer to IEC standard definitions for the operating modes like power production, startup, or emergency shut down, as well as the wind and grid conditions that are intended for the tests. With this framework and standardized definitions, test facilities will be capable of performing tests with comparable loading conditions. The framework for the test load cases was developed in 2015 and will be used to define the operating modes in combination with wind models and grid conditions, including mechanical and electrical faults (see Figure 2).

### 3.2 Subtask blade

In 2015, the rotor subgroup continued collaboration and work in four primary activities around blade and blade-subcomponent test development:

1. Blade test methods
2. Subcomponent testing
3. Nondestructive inspection
4. Uncertainty analysis of blade testing

Each of these primary activities is intended to provide new or updated information to guide improvements in the function and quality of rotor blade test methods. The Technical University of Denmark (DTU) is leading wind turbine blade test methods. Fraunhofer-IWES leads the subcomponent testing activity. Sandia National Laboratories leads the nondestructive inspection activity and the National Renewable Energy Laboratory leads the blade test uncertainty estimation and analysis. In 2015, collaboration and understanding advanced in all activities of the subgroup.

Significant work was accomplished in 2015 for the uncertainty analysis for blade testing. Detailed comparisons were conducted on the approaches used to quantify strain-to-bending moment sensitivities for calculation of applied bending moments and fatigue damage equivalent loading. Additional uncertainty influences including combinations of flapwise, lead-lag, and torsional loads were evaluated.

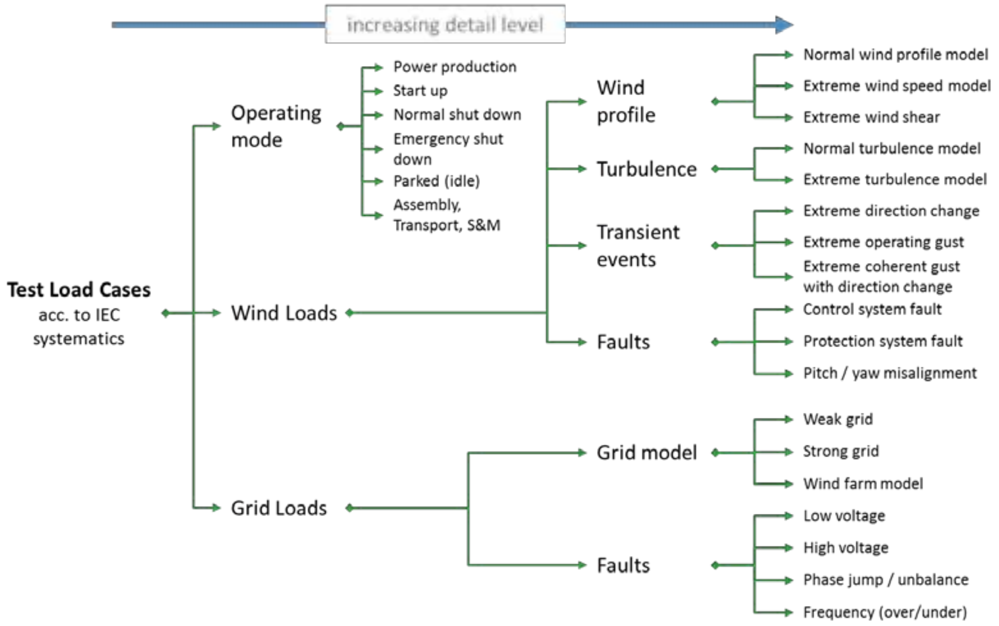


Figure 2. Framework of test load cases

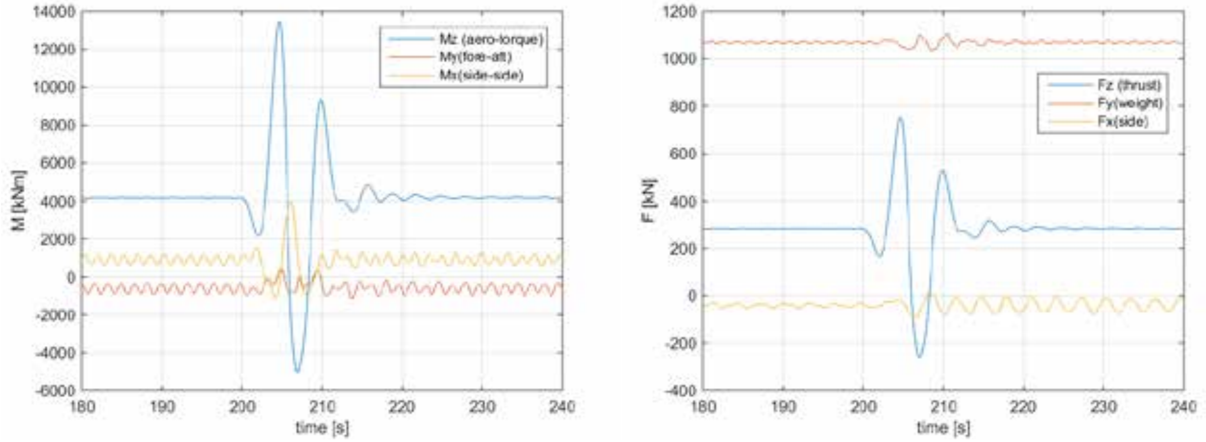


Figure 3. Extreme operation gust: a) moments in main bearing, b) forces in yaw bearing (simulation example by DTU)

## 4.0 Plans for 2016 and Beyond

### 4.1 Subtask nacelle

In 2016, the nacelle subtask will select the load cases for the robustness tests and controller optimization. According to DTU's approach, for robustness tests the wind turbine manufacturer should provide the design load calculations of the components according to the IEC-61400-1 standard prior test planning. The test load cases will be based on these simulated loads at different operating modes, transient events and faults (e.g., pitch misalignment, grid loss, and extreme gusts). The simulation results will then be analyzed in terms of maximum loads on the drivetrain and its dynamics such as frequency and amplitudes (see Figure 3).

In testing, the relevant extreme loads are applied to the drivetrain in order to identify weak spots and evaluate the robustness of the powertrain against faults like pitch misalignment or grid loss. Eventually, the nacelle subtask will define test dependent stop criteria such as an occurring failure mode or a survived load program.

Although full nacelle testing is the focus of Task 35, there is a demand for subsystem testing such as robustness and life testing of gearboxes or main bearings, and electrical certification for the generator or power electronics.

### 4.2 Subtask blade

Building upon the framework developed in 2015, the blade subtask will focus on comparison and analysis of each sub-activity in 2016.

The blade test methods activity will include evaluation of different methods used for property characterization, static and fatigue testing, and processing and validation of data. The test loads considering load acceleration will be assessed in greater detail, and control and workplace safety practices will be evaluated. Special attention and evaluation of biaxial test methods will also be performed.

The nondestructive inspection (NDI) activity will include a comparison of new sensing technologies and candidate NDI methods. Advantages, limitations, and deployment opportunities of sensing methods will be compared and the use of NDI for evaluating manufacturing variances will be described.

The subcomponent activity will focus on making subcomponent procedures and results useable and understandable to test engineers and blade designers. This activity will also describe subcomponent configurations with consideration of boundary conditions.

Blade test uncertainty analysis work will continue with the development of calibration methods for fatigue tests. Comparison and evaluation of calibration methods, and procedures needed for fatigue biaxial testing will be considered in detail.

**References:**

Opening photo: Collage of test centers participating in Task 35

[1] Areva; www.areva.com/EN/news-9108/offshore-wind-turbines-arevas-5-megawatt-full-load-test-benchin-operationsinceoctober2011.html; Accessed 23 November 2011

[2] Vestas; worldofwind.vestas.com/en/verification-testing; 17 January 2013

Authors: Dennis Bosse and Georg Jacobs, Center for Wind Power Drives at RWTH Aachen University, Germany; and Scott Hughes, National Renewable Energy Laboratory (NREL), United States.

# 16 Task 36

## Forecasting for Wind Energy

## 1.0 Introduction

Task 36 focuses on improving the value of wind energy forecasts for the wind industry. Wind power forecasting on the hour scale functions using only online data from wind farms. However, the forecasting horizon needed when power is traded in the markets is typically day-ahead, which requires the use of weather models. Previous research has shown that most of the day-ahead forecast error comes from the Numerical Weather Prediction (NWP) models.

Forecasting the chaotic behavior of the atmosphere remains a primary challenge of the atmospheric sciences. Because atmospheric motions occur on distance scales ranging from 1 mm to $10^4$ km (10 orders of magnitude), it is not feasible to explicitly forecast the evolution of the atmosphere at all scales at once. Consequently, prognostic numerical models generally resolve a range of scales encompassing the phenomena of interest, and the smaller scales are parameterized.

Mesoscale atmospheric models are not only used for general weather forecasts but also to provide short-term wind forecasts. In these models, parameterizations are used to represent processes occurring on horizontal scales less than the grid spacing explicitly resolved by the models (1–10 km). Assumptions are made about the dominant physical processes on unresolved scales and may be adjusted according to observations. It is thus possible to “tune” physical models of the atmosphere to optimally reproduce a phenomenon of particular interest (such as movement of weather fronts and associated precipitation) while less optimally reproducing other phenomena (such as winds at 100 m above the surface). In addition, mesoscale models often offer multiple parameterizations for a particular process, each reflecting a different concept of which unresolved processes are dominant. This allows the modeler to choose which specific set of parameterizations to use. Finally, to create a forecast, a model must be initialized with observations. The combination of initialization errors and the highly non-linear governing equations of the models lead to additional errors in the forecasts.

There are three distinct areas of challenge in forecasting wind power. The first is in the continuing effort to improve the representation of physical processes in forecast models through both improved initialization and improved parameterizations. The second area is the representation of uncertainty, the lack of uniform benchmark criteria, and the lack of benchmarks or comparison datasets. A third area is representation, communication, and use of these uncertainties presented to industry in forms that readily support decision-making in plant operations and electricity markets. This task will facilitate efforts in all three of these areas and work to define best practices for model evaluation and uncertainty communication.

Figure 1. Participants of the kick-off meeting in Risø, January 2016 (Source: Gregor Giebel)

## 2.0 Objectives and Strategy

Task 36 consists of three work packages: Work Package 1 aims at improving Numerical Weather Prediction models and is led by Helmut Frank of Deutscher Wetterdienst and Will Shaw from Pacific Northwest National Laboratory. Work Package 2 will analyze the uncertainty and predictability of power forecasting models and establish a good practice for benchmarking. Bri-Mathias Hodge of the National Renewable Energy Laboratory and Pierre Pinson of the Technical University of Denmark lead this work. Finally, Work Package 3 is aimed at the end users, with the objective to provide the best probabilistic forecasts information. The third work package is led by Georges Kariniotakis of MINES ParisTech and Jens Madsen from Vattenfall.

## 3.0 Progress in 2015

The task was approved in principle by the IEA Wind Executive Committee in May 2015. The remainder of the year was spent consortium-building. The task’s kick-off meeting took place in January 2016 in Risø, Denmark (Figure 1).

## 4.0 Plans for 2016 and Beyond

Task participants are working on publication of several reports dealing with improvements in Numerical Weather Prediction models. One report mapping the current knowledge gaps will be discussed in a public workshop in Barcelona on 9 June 2016. Another report will map existing data that could be used for either benchmarking of weather models or as input data to them, with a special emphasis on tall towers. Ongoing meteorological experiments will also be mapped, such as the instrumentation of the Columbia

**Table 1. Countries and Organizations Participating in Task 36 During 2015**

| | Country/Sponsor | Organization(s) |
|---|---|---|
| 1 | Denmark | Technical University of Denmark (DTU); Danish Meteorological Institute (DMI); DNV GL; ENFOR; WEPROG; Energinet.dk; Vestas |
| 2 | Finland* | VTT; Vaisala |
| 3 | France | MINES ParisTech; MeteoSwift; EDF; CNR; Maia Eolis |
| 4 | Germany | Deutscher Wetterdienst; Fraunhofer IWES; ForWind; ZSW |
| 5 | Ireland | Dublin Institute of Technology; University College Dublin |
| 6 | Norway* | NORCOWE; Kjeller Vindteknikk |
| 7 | Portugal* | INESC TEC; Prewind; Smartwatt; LNEG |
| 8 | Spain* | Vortex; Iberdrola Renovables; EDP Renovaveis |
| 9 | Sweden | Vattenfall |
| 10 | UK | MetOffice; Reading University; UK National Grid |
| 11 | United States | United States Department of Energy;<br>Pacific Northwest National Laboratory;<br>National Renewable Energy Laboratory |

*Countries which have submitted an official letter of participation

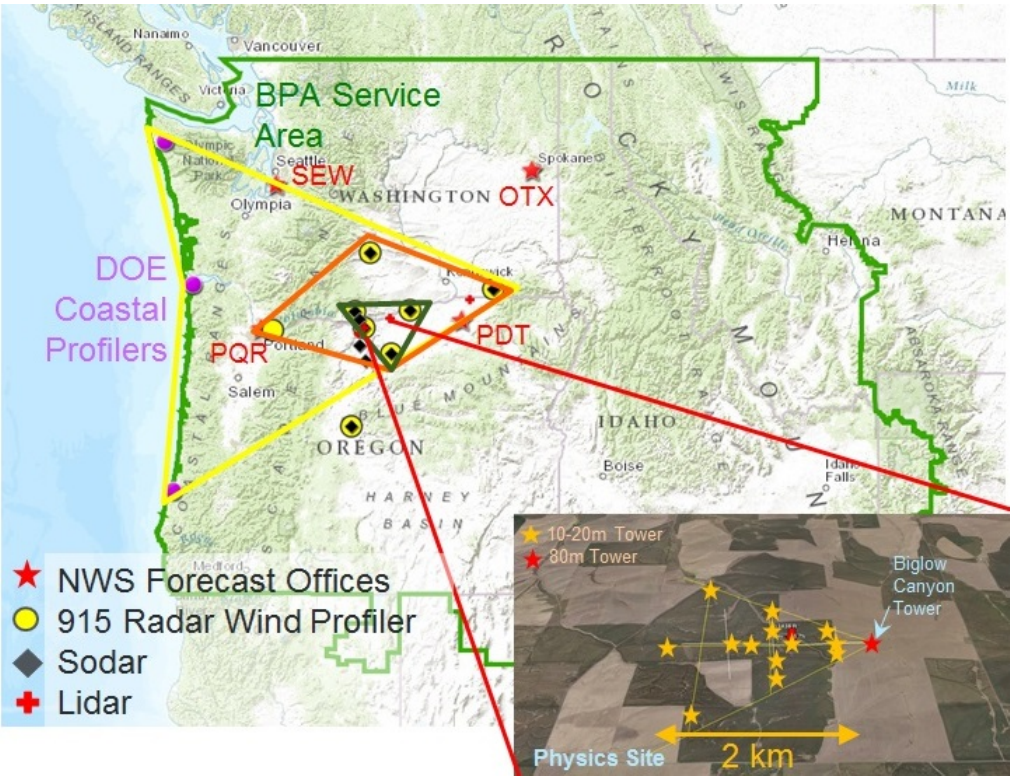


Figure 2. The instrumentation of WFIP2 in the northwest United States (Source: Joel Cline)

Gorge (United States) in the Wind Forecast Improvement Program 2 (WFIP2) or the planned experiments for the New European Wind Atlas (NEWA), as shown in Figure 2. Eventually, these data sets will be used to set up a meteorological benchmarking experiment for all task participants.

The second work package is focused on the particulars of benchmarking processes and the main outcome of this effort will be an IEA Wind Recommended Practice on wind power forecast evaluation. The report will examine appropriate error measures, as well as how to set up a benchmarking process (e.g., find a suitable provider of wind power forecasts for a company). Another major activity in this work package will be the execution of benchmarks, taking probabilistic forecasting into account.

Finally, in Work Package 3, probabilistic forecast use cases and scenarios will be collected and a position paper on the best use of probabilistic forecasts will eventually follow.

**References:**

Opening photo: Control Centre of Renewable Energy of Red Electrica de España (Source: http://ree.es/en/press-office/image-gallery/electricity-control-centre)

Author: Gregor Giebel, DTU Wind Energy, Risø, Denmark.

# 17 Task 37

## Wind Energy Systems Engineering: Integrated Research, Design, and Development

## 1.0 Introduction

**Over the last few decades, wind energy has evolved into a large international industry involving major players in the manufacturing, construction, and utility sectors. Significant innovation in the technology has resulted in larger turbines and wind plants with lower associated costs of energy. However, the increasing importance of wind energy's role within the electricity sector imposes more requirements on the technology in terms of performance, reliability, and cost. To address these changing expectations, the industry has made efforts that focus on achieving a variety of goals including reducing installed capital costs for the turbine and plant, decreasing the downstream costs for operation and maintenance (O&M), increasing energy production, and minimizing negative external environmental impacts such as noise emission or habitat disruption.**

**In many cases, these goals involve trade-offs. For example, up-front investment in a robust component design may avoid large downstream costs for component repair and replacement. In another case, the design of a machine with a higher tip speed can reduce required torque and loads through the drivetrain, but at the same time these higher tip speeds can lead to more aero-acoustic noise that adversely impacts surrounding communities. Trade-offs and techno-economical conflicts such as these exist throughout the entire system.**

**The purpose of IEA Wind Task 37 is to apply a holistic, systems engineering approach across the entire wind energy system. An integrated approach is needed to fully assess how a change, or an uncertainty, in a design parameter affects the myriad of objectives in system performance and cost. Integrated systems research, design, and development can provide opportunities for improvements in overall system performance, and reduction in the levelized cost of energy. However, there are significant challenges to developing such integrated approaches, both within and across organizations. There is a need to explore both the opportunities and the challenges for applying systems engineering to integrated wind energy research, design, and development across the entire wind energy system. This need surfaces both in the tools and methods used in wind plant research, design, and development.**

**Previous efforts of IEA Wind Tasks such as Task 30 OC3 and OC4 and experience with the 5-MW reference turbine at the National Renewable Energy Laboratory (NREL), show that effective coordination can be achieved by providing frameworks such as reference designs and reference cases for analysis.**

**IEA Wind Task 37 goes one step further—in addition to providing a forum for reference system (wind turbines and plants) development and multi-disciplinary design analysis and optimization (MDAO) benchmarking activities, the task will provide framework guidelines that will enable more seamless integration of analysis tools and reference models between organizations.**

**Participants that have joined Task 37 to date are listed in Table 1.**

## 2.0 Objectives and Strategy

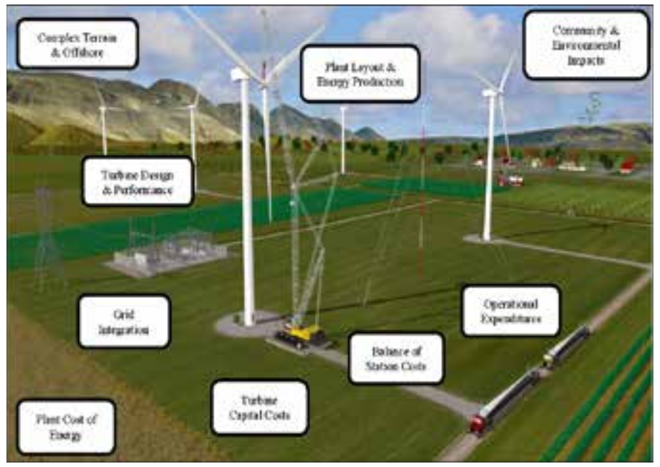
To fully assess how one change in a design parameter affects the myriad of objectives in system performance and cost, a holistic and integrated approach is needed. Integrated system research, design and development can provide opportunities for improvements in overall system performance and reductions in overall cost of energy.

The objective of this task is to improve the practice and application of systems engineering to wind energy research, design, and development. This will be achieved through a set of coordinated international research activities that move the wind energy research, design, and development community towards the analysis of wind power plants as holistic systems.

Explicit goals of the task are to:

- Promote general knowledge and understanding of systems engineering tools and methods and the overall value of these to wind energy research, design, and development,
- Improve quality of systems engineering by practitioners,
- Enable better communication across researchers and practitioners in different disciplines,
- Enable system-level analysis including technology evaluation, MDAO, multi-fidelity modeling, and uncertainty analysis and quantification, and to
- Promote enhanced design of wind turbines and plants through the use of system engineering tools and methods.

Expected results of the effort will include guidelines to support integration of analytical capabilities for modeling wind turbine and plants, reference wind turbine and plant models that may be used by the entire wind energy research, design, and development community, and reports on best practices in performing MDAO analysis of wind turbines and plants.



To accomplish these objectives three work packages are underway, each addressing both turbines and wind plants:

1. Guidelines for a common framework for integrated research, design, and development at different fidelity levels
2. Reference wind energy systems
3. Benchmarking MDAO activities at different system levels

## 3.0 Progress in 2015

IEA Wind Task 37 was approved in principle in May 2015 by the IEA Wind Executive Committee and the task officially began in early January of 2016.

A task kick-off meeting was held at the Technical University of Demark Wind Energy to complete the work plan. Eighteen participants attended the three-day meeting where the overall task objectives and each work package was discussed in detail. Concrete activities for the first year were specified including the likely participants in each of the work package tasks. The final work plan was approved at the 76th IEA Wind Executive Committee meeting in October 2015.

**Table 1. Countries and Organizations Participating in Task 37 During 2015**

| | Country/Sponsor | Organization(s) |
|---|---|---|
| 1 | Denmark | DTU Wind Energy; Vestas Wind System A/S; Siemens Wind Power |
| 2 | Germany | Fraunhofer IWES; Technische Universitat at Munche;, University of Stuttgart; Nordex Energy GmbH |
| 3 | Netherlands | ECN Wind Energy; Delft University of Technology; DNV GL |
| 4 | Norway | SINTEF Energy Research; Chirstian Michelsen Research; Uni Research |
| 5 | Spain | CENER; National Renewable Energy Center of Spain |
| 6 | UK | BVG Associates Ltd.; DNV GL; ORE Catapult |
| 7 | United States | National Renewable Energy Laboratory; Brigham Young University; Siemens Wind Power; GE Global Research; Sandia National Laboratories; University of Texas at Dallas |

## 4.0 Plans for 2016 and Beyond

All three work packages began execution of the approved work plan January 2016.

Work Package 1 acknowledges that there are many efforts within industry and research communities to integrate wind turbine and plant models into frameworks to support MDAO activities. The effort here begins with the task of finding a common ontology (hierarchical framework of characteristics) for these types of models to enable more collaboration and integration across the different community stakeholders. This will involve surveying current frameworks as well as establishing a common ontology and set of guidelines. The work will provide a basis for the reference wind energy system and benchmarking activities to follow.

Work Package 2 will coordinate the development of a small set of reference wind turbines and wind power plants that will serve as baseline cases for international research. Ultimately, this work will lead to a definition of a series of reference turbines and wind plants that reflect current technologies, representative of what may be constructed over the next decade.

Work Package 3 will provide a systematic overview and evaluation of different modeling and optimization approaches to MDAO of wind turbines and plants. This will be achieved through a series of benchmarking problems defined collaboratively by the project participants. The scope of these benchmarking problems will be established with the help of a participant survey to provide an overview of participant simulation codes and frameworks. The survey will involve collecting information on state-of-the-art MDAO research and software for wind energy applications. Also in year one, an overall process and evaluation criteria for the benchmarking work package will be established and a plan for the first phase of turbine and plant benchmarking studies will be completed.

**References:**

Opening photo: An example of a wind plant—a complex and highly interconnected system (Graphic: Alfred Hicks, National Renewable Energy Laboratory)

Authors: Katherine Dykes, National Renewable Energy Laboratory, United States; Pierre-Elouan Réthoré and Frederik Zahle, Danish Technical University Wind Energy, National Laboratory For Sustainable Energy, Denmark; and Karl Merz, SINTEF Energy Research, Norway.

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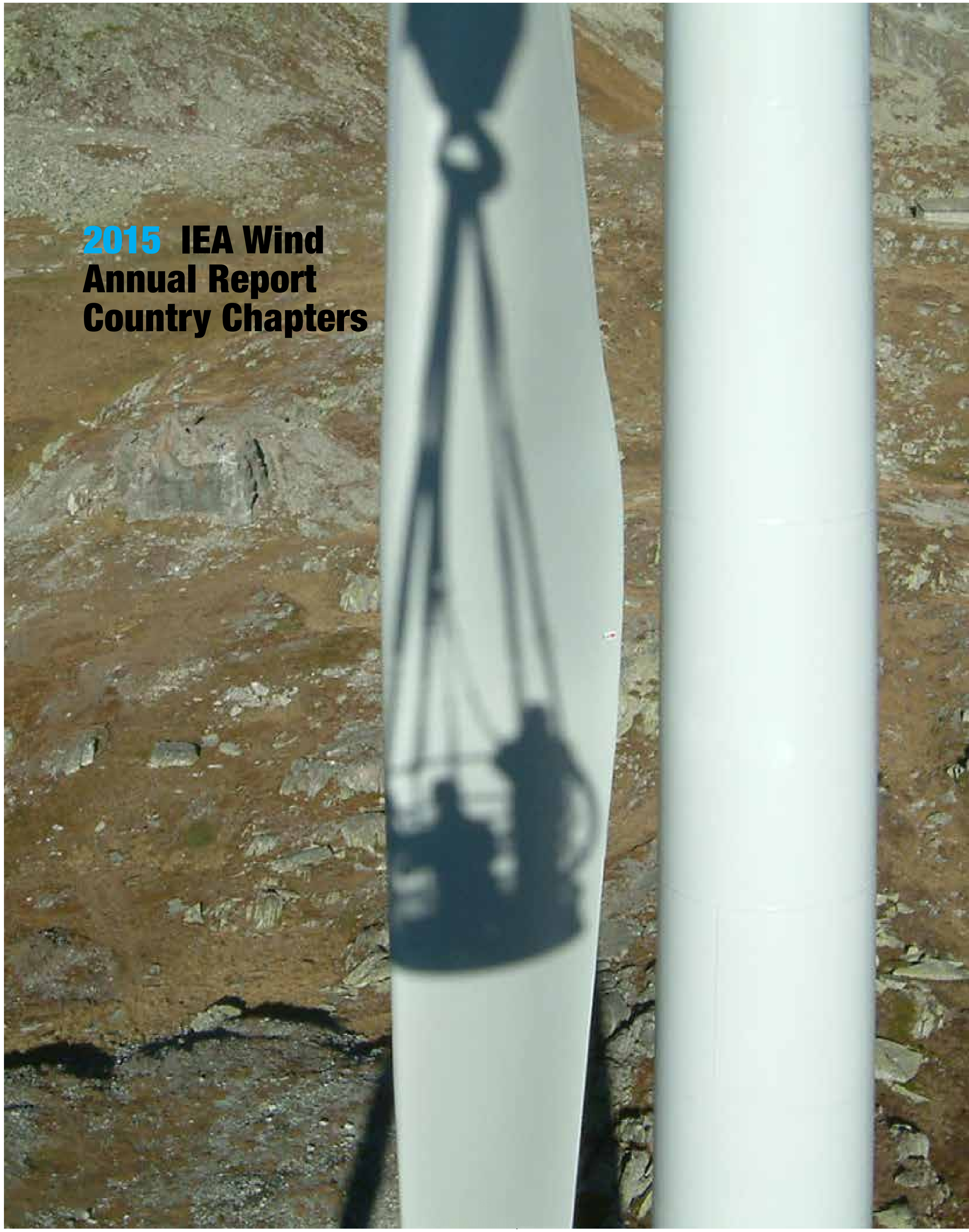

# 2015 IEA Wind Annual Report Country Chapters

# 18 Austria

## 1.0 Overview

**With nearly 70% of renewable energy in its electricity mix, Austria is among the global leaders in this respect. Without any doubt, the natural conditions in Austria—hydropower, biomass, and a high wind energy potential—allowed such a development. For the fourth year in a row, wind energy in Austria increased by more than 300 MW, reaching an all-time high with 323 MW (Table 1).**

**By the end of 2015, nearly 2,409 MW of wind power were operating in Austria. Burgenland, the easternmost of Austria's nine federal states, reached its goal and now generates enough electricity from wind power to cover more than the overall annual energy usage of the state.**

## 2.0 National Objectives and Progress

The Ökostromgesetz (GEA), adopted in 2012, launched a significant expansion in wind power installations in the following years. This law maintained the existing feed-in-tariff (FIT) system and established a 2020 target of 3,000 MW by adding 2,000 MW of wind power to the capacity of 2010 (1,011 MW).

The FIT must be set by an ordinance of the Minister for Economic Affairs and is not fixed in the GEA itself, if not it decreases automatically by 1%. Tariffs for two years were fixed by the ministries for the first time at the end of 2013, bringing some certainty for investors. The FIT for 2014 was fixed at 0.0935 EUR/kWh (0.1017 USD/kWh); for 2015 it is fixed at 0.0927 EUR/kWh (0.1009 USD/ kWh). Now, the tariff for 2016 will be 0.0904 EUR/kWh (0.0984 USD/kWh) and 0.0895 EUR/kWh (0.0974 USD/kWh) in 2017.

### 2.1 National targets

The GEA 2012 adheres to the existing target of 15% of renewable energy supply (without large hydro) and a specific target of an additional 700 MW of wind power capacity by 2015 (an increase to 1,700 MW). This target was already reached in the first quarter of 2014 (Figure 1). However, the GEA 2012 also established a long-term target of adding 2,000 MW of wind power to the existing capacity (1,011 MW) by 2020—a target of 3,000 MW by 2020.

This target is higher than Austria's target for wind energy in its National Renewable Energy Action Plan (NREAP). In the NREAP (according to European Union directive 2009/28/EC), Austria set a target of 1,951 MW by 2015 and 2,578 MW by 2020.

In a 2014 study, the Austrian consultant Energiewerkstatt (www.energiewerkstatt.org) estimated that a total wind power capacity of 3,808 MW (annual production of 9 TWh) could be achieved by 2020 and a total capacity of 6,649 MW by 2030 (annual production of 17.7 TWh).

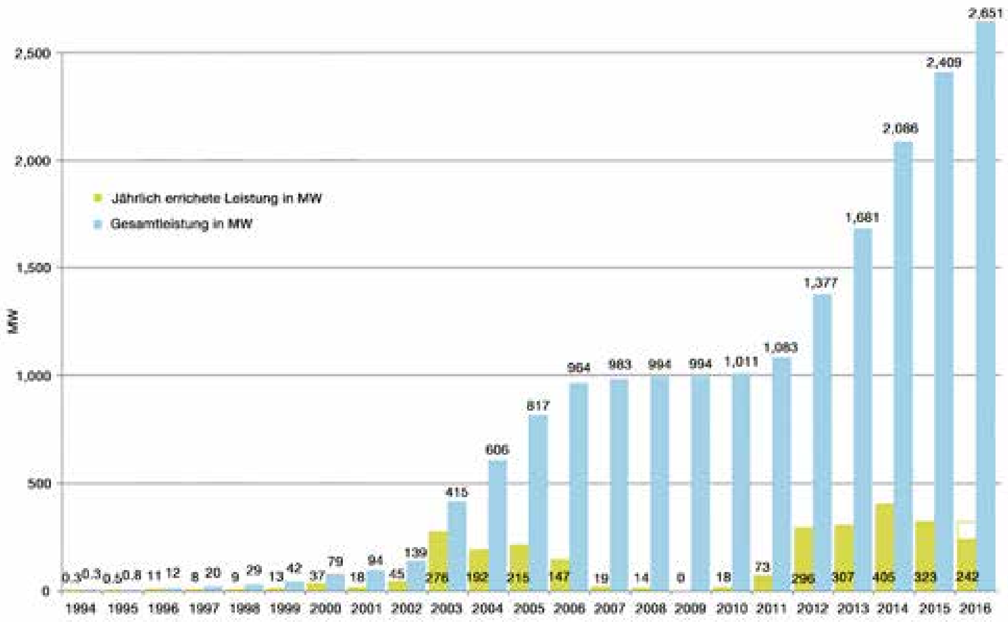

Figure 1. Cumulative installation of wind power in Austria

### 2.2 Progress

The large expansion of wind power installations began in 2012 (Figure 1). At the end of 2013, 1,684 MW of wind capacity were installed in Austria, counting for an annual production of around 3.6 TWh of electricity production. By the end of 2014, the capacity increased to 2,095 MW or, with 4.5 TWh electricity produced, 7.2% of the Austrian electricity demand (end energy consumption of households). In 2015, new installations reached 323 MW and led to a cumulative installed capacity of 2,409 MW, covering 8.7% of the electricity consumption.

The installed capacity is able to produce more than 5.2 TWh/yr. With an estimated 2,651 MW in 2015, the annual production of all Austrian wind turbines accounted for approximately 9% of the Austrian electricity demand and avoided approximately 3.9 million tons of $CO_2$ emissions.

Most wind turbines (1,248 MW) are still installed in Lower Austria, followed closely by Burgenland (985.7 MW), Styria (125.6 MW), Upper Austria (41 MW), Vienna (7.4 MW), and Carinthia (0.5 MW), as shown in Table 2.

### 2.3 National incentive programs

#### 2.3.1 GEA 2012

The 2002 adoption of GEA triggered investments in wind energy in 2003–2006. Subsequently, an amendment in 2006 brought uncertainty to green electricity producers as well as new restrictions for projects. This led to nearly four years of stagnation of the wind power market in Austria. A small amendment to the GEA in 2009 and a new FIT set in 2010 (0.097 EUR/kWh; 0.106 USD/kWh) improved the situation.

In July 2011 the Austrian parliament adopted GEA 2012 providing new legislation for electricity from renewable energy sources. This law continues the FIT system, but for the first time establishes a stable legal framework through 2020, with a target of adding 2,000 MW of wind power to the existing capacity (1,011 MW) by 2020. However, there are still restrictions for new projects; those projects only get a purchase obligation and a FIT if they get a contract with the Ökostromabwicklungsstelle (OeMAG), the institution in charge of buying green electricity at the FIT and selling it to the electricity traders.

The OeMAG has to give contracts to green electricity producers as long as there are enough funds for new projects. The budget started with 50.0 million EUR/yr (54.4 million USD/yr) for new projects. This is enough for approximately 120 MW to 350 MW of new wind capacity per year depending on the market price for electricity and the applications from photovoltaics and small

**Table 1. Key National Statistics 2015: Austria**

| | |
|---|---|
| Total (net) installed wind capacity | 2,409 MW |
| New wind capacity installed | 323 MW |
| Total electrical output from wind | 5.2 TWh |
| Wind-generated electricity as a % of national electric demand | 8.7% |
| Target: | 3,000 MW wind power by 2020 |

**Table 2. Wind Power Capacity of the Federal States**

| Federal State | Capacity (MW) | Turbines |
|---|---|---|
| Lower Austria | 1,248.0 | 602 |
| Burgenland | 985.7 | 412 |
| Styria | 125.6 | 67 |
| Upper Austria | 41.4 | 28 |
| Vienna | 7.4 | 9 |
| Carinthia | 0.5 | 1 |
| **Austria** | **2,408.6** | **1,119** |

hydropower plants. However, this budget decreases by 1.0 million EUR/yr (1.1 million USD/yr) for first ten years the law is active. After a positive state-aid decision of the European Commission, the GEA 2012 became law on 1 July 2012

#### 2.3.2 Green Electricity Regulation–Ökostromverordnung 2012

The FIT is still set by an ordinance and is not fixed in the GEA 2012 itself. The FITs are fixed in the Ökostromverordnung/Green Electricity Regulation by the Minister of Economy in accordance with the Minister of Environment and the Minister of Social Affairs. The tariffs are guaranteed for 13 years. The purchase obligation is limited to a specific amount of capacity—depending on the available funds for new projects. The tariff for 2016 will be 0.0904 EUR/kWh (0.0984 USD/kWh) and 0.0895 EUR/kWh (0.0974 USD/kWh) in 2017.

### 2.4 Issues affecting growth

The most crucial factors for the growth of wind power capacity are the amounts of the FIT, the stability of the incentive program, and the annual amount of money for new projects (annual funds). Due to the adoption of the GEA 2012, the determining factor for wind power growth will be the amount of the FIT. Because the tariffs are fixed for two years, some stability is guaranteed. But with the growing demands from the grid providers, the installation costs are expanding rapidly and constrain growth.

Another issue is the rising costs for project development and growing burdens coming from ancillary services which rose from 89 million EUR (97 million USD) in 2011 to more than 200 million EUR (218 million USD) in 2014. Rising costs are mainly the result of market failure. Unlike the situation in most of Europe, power producers bear a major share of the ancillary cost ("g-component"), which decreases competitiveness, especially of renewables (Table 3).

## 3.0 Implementation

### 3.1 Economic impact

The Austrian wind power market is made up of wind turbine operators and planning offices as well as component suppliers for international wind turbine manufacturers. In 2013, (the latest year with statistics available) the annual turnover of operators of existing wind parks was over 330 million EUR (359 million USD).

Austria's wind energy industry includes more than 170 supplier and service companies. These are leading companies in the fields of conducting, wind power generators, wind turbine generator design, and high tech materials. Moreover, Austrian service providers such as crane companies, planning offices, and software designers work extensively abroad. Local companies are successful both in the land-based and the offshore sector. At the same time, many wind energy operators have taken the step abroad to be able to realize their know-how on a global level.

Following a study conducted by the Austrian Wind Energy Association, one-third of the Austrian industry in the wind energy supply chain exports with a volume of more than 660 million EUR (718 million USD). This strongly increasing tendency is reflected in growth rates between 20–25% of their turnover.

### 3.2 Industry status

Cooperatives own 20% of all existing wind turbines, and another 40% are owned by utilities. The rest are owned by private companies. The first wind turbines in Austria where built in 1994 when cooperatives or single wind turbines built by farmers were most common. With a more stable incentive system since 2000, but especially since 2003, utilities and other companies entered the market. The Austrian operators are very active in the neighboring countries of central and eastern Europe, and some independent companies have also started businesses outside Europe. There are no major manufacturers of wind turbines in Austria, however there are manufacturers of small (micro) wind turbines.

Austrian component suppliers also serve the international wind turbine market. Bachmann Electronic GmbH is a leading manufacturer of turbine control systems. Hexcel Composites GmbH develops and produces materials for blades. Elin EBG Motoren GmbH is an important supplier for the global market for generators. There is also a number of global players with wind competence centers in Austria. A well-known company is, for example, SKF.

Fostered by the growth of the domestic market, the number of small and medium enterprises (SMEs) entering the market increased over the past few years. Due to the economic structure of the Austrian industry, there is a significant potential for high quality products in the software, service, and component sectors, which is partially transferred from the automotive and aerospace industry.

### 3.3 Operational details

Most of the turbines in Austria are 1.8 MW to 2.3 MW in capacity, but since 2013 more than 80% of new installations are 3-MW turbines or larger, leading to an average size of newly installed capacity of 3 MW in 2015.

**Table 3. Cost of New Wind Energy Projects**

| | EUR/kW | USD/kW |
|---|---|---|
| Total investment costs | 1,1715.00 | 2,077.00 |
| Turbine costs | 1,390.00 | 1,512.32 |
| Incidental costs (planning, connection to grid and grid reinforcement, etc.) | 325.00 | 353.60 |
| O&M costs average | 0.020 | 0.022 |

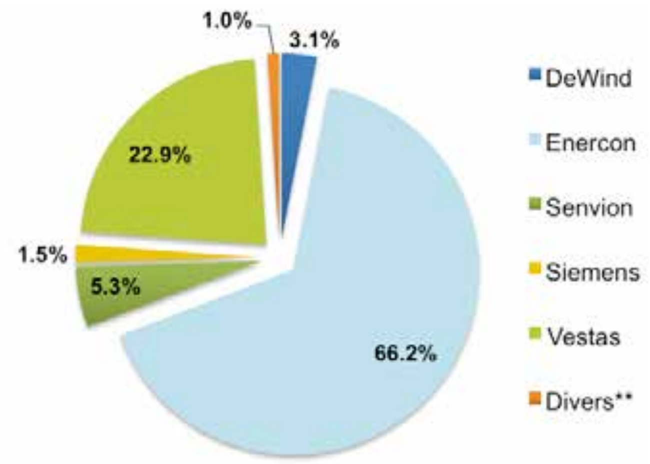

Figure 2. Market shares of wind turbine manufacturers in 2015

Enercon and Vestas are the dominant suppliers of turbines (Figure 2). Enercon and Energie Burgenland Windkraft GmbH built two of the largest wind turbines in the world—E-126 models rated at 7.5 MW each. In 2013, Windkraft Simonsfeld built the tallest turbine in Austria. The 3.2-MW turbine reaches a total height of 200 m (tower plus blade).

## 4.0 R, D&D Activities

### 4.1 National R, D&D efforts

In 2015 two research projects received public funding: the "Observation of Ice-falling-events Project" aims at improved understanding of the risk of ice fall from wind turbines by generating a database of ice-falling events from wind turbines in flat, semi-alpine, and alpine locations. The "Urban Small Wind Power Project" addresses the challenges of installation and operation of small wind turbines in urban, highly-turbulent areas.

At the end of 2015 two additional national research projects were approved for funding. Both of them deal with the challenges of icing of wind turbines: project "R.Ice" is addressing risk-related issues, and project "IceControl" focuses on improving the meteorological prognosis of icing events.

### 4.2 Collaborative research

In 2009, Austria joined IEA Wind Task 19 Wind Energy in Cold Climates. The national research activities included in the task's fourth term focused on the following three aspects:

- Evaluation of different ice detection systems,
- Comparison of the legislative requirements in the partner country in terms of ice-throw risk assessments, and
- Evaluation of the operational performance of a stand-alone power supply unit for an intelligent, demand-oriented energy supply for heated wind measurement sensors.

In 2013, Austria joined IEA Wind Task 27 Small Wind Turbines in High Turbulence Sites. The cooperation will continue until the end of February 2016. Also, at the end of 2015, funding was granted for the upcoming term of IEA Task 19 as well as for a participation in Task 32 LIDAR: Lidar Systems for Wind Energy Deployment.

## 5.0 The Next Term

The GEA 2012 and the FIT for 2015 provide a solid basis for the further development of wind power in Austria. It will be crucial for the growth of wind power capacity for measures to be taken for grid reinforcement and growth in the eastern part of Austria. Furthermore, Lower Austria passed new zoning restrictions. The installation of new wind farms is restricted to less than 2% in that federal state. It is questionable whether Lower Austria can achieve the renewable energy goals set out in its 2030 energy road map.

A serious uncertainty is imposed by the unclear future of the GEA 2012 because the circumstances under which it was implemented have changed (i.e., dramatic increase of costs for ancillary services and market prices well below 0.030 EUR/kWh; 0.032 USD/kWh). Another political uncertainty comes from the new state aid guidelines from the European Commission, which threaten an economic and stable growth of wind energy as well as for the companies in the supply chain.

Due to the fact that the green electricity act defines an annual budget for wind power, which is currently limited by the low market price for electricity and high cost for balancing energy, the budget available for installations has decreased significantly. Currently, 700 MW of capacity is on this waiting list. The GEA defines a maximum waiting list of three years which imposes a high risk for those projects, thus massively hampering investment.

### References:

Opening photo: Munderfing Windpark (Photo credit: EWS Consulting)

Authors: Florian Maringer, IG Windkraft and Andreas Krenn, Energiewerkstatt, Austria.

# 19 Belgium

## 1.0 Overview

**In Belgium renewable energy competences are divided between the federal and the regional levels. Offshore wind policy is a federal matter, while land-based wind policy is a regional matter. Belgium has three regions: the Brussels-Capital Region, the Flemish Region, and the Walloon Region. In 2014 the former Belgian government decided to become a member of the IEA Wind Technology Collaboration Programme.**

**In 2003, the federal government began building the first Belgian offshore wind park in the North Sea. In May 2004, a 156-km$^2$ area outside the 12-mile zone was created in international waters in the Belgian exclusive economic zone for wind parks (Figure 1). At the end of 2015, 182 offshore wind turbines were operational producing 2,475 TWh/yr in three parks. C-Power and Northwind parks are fully operational and the first phase of Belwind park has 55 turbines operating. In 2015, Belgian offshore wind capacity can provide electricity to approximately 800,000 families.**

**The country has plans to reach 2,200 MW (6.6 TWh) of wind generation in 2020, which amounts to 50% of the household Belgian electricity use and is 7% of the gross final electricity use. Due to low public acceptance of the connection from offshore parks to the shore (Stevin Connection), 2015 was a relative stable year regarding added capacity (Table 1).**

**Belgium is a frontrunner when comparing installed capacity with the available space, the bathymetry, and the distance from shore. Excellent researchers and research institutions place Belgium as a leader in wind power. The offshore zones are also perfect for research purposes, for example, with the test zone for the Alstom-Haliade 150-6-MW offshore wind turbine.**

## 2.0 National Objectives and Progress

### 2.1 National targets

The land-based and offshore wind energy developments are essential for the Belgian and European targets for energy development from renewable energy sources. By 2020, the total land-based installed capacity in Belgium should reach 3,000 MW, and an additional 2,271 MW is planned offshore, for a possible total of 5,271 MW of wind power. This will help achieve the target of 13% of renewables in final gross energy consumption by 2020 per the renewable energy directive [1].

### 2.2 Progress

Table 2 shows offshore wind electricity generation was first installed in 2009 and progressed rapidly to a total of 712 MW in 2015. Belgium is working quickly to reach the 2020 targets, although some social acceptance problems with the land-based connection caused delays in 2015. This matter has been resolved and Belgium expects increases in offshore installation in 2016 and certainly in 2017.

Regarding land-based wind, the total capacity remained low until 2004 when the installed capacity and production started to double year after year from 96 MW in 2004 to 1,517 MW in 2015. Land-based wind is on track to reach its 2020 objectives after much progress during the last few years (Table 2 and Figure 2).

As shown in Figure 2, the share of wind generation in gross electricity production has sharply increased since 2009 with the installation of the offshore windpark C-Power. Land-based wind also made progress with large amounts of wind coming online since 2009. In 2015, wind production increased greatly during the last few months due to good wind resources and full capacity use for most of the wind parks (Figure 3).

In addition to adding sustainable energy capacity, offshore wind energy developments also increase biodiversity in the sea. The foundations of the wind turbines form artificial reefs, where, among other things, mussels grow. The foundations also contribute to the growing fish population providing many opportunities to further develop the marine culture in the Belgian North Sea. At the end of 2015, the installed capacity possible in this zone for wind parks is estimated at more than 2,200 MW. This would mean a production of more than 7.70 TWh without $CO_2$ emissions, fulfilling 10% of the national electricity demand.

### 2.3 National incentive programs

In general, Belgium's renewable energy policy is aligned with the EU 2020 targets. For 2020, Belgium has a binding national target for renewable energy to equal 13% of gross final consumption of energy.

Regarding offshore wind power, the transmission system operator (TSO), Elia, is obligated to buy the green certificates from the generators at a minimum price set by federal legislation. The purchase agreements must be approved by the regulator, CREG. This system was established in 2002 and was amended in 2014 as follows:

- For installations with a financial close up to 1 May 2014: the minimum price is 107 EUR/MWh (116 USD/MWh) for electricity originating from the first 216 MW of installed capacity, and 90 EUR/MWh (98 USD/MWh) for volumes from above 216 MW of capacity.
- For installations with a financial close after 1 May 2014: the minimum price is calculated as follows: minimum price equals the Levelized Cost of Electricity (LCOE) – [reference wholesale price of electricity – correction factor]. The LCOE is equal to 138 EUR/MWh (150 USD/MWh); the correction factor is equal to 10% of the reference wholesale price of electricity. The value of these parameters can be adapted for each installation. The minimum prices are reviewed every three years.

The purchase obligation applies for a period of 20 years. (*Note: these rules are subject to possible changes in the coming months or years). As long as there is no market for these offshore green certificates, they remain in effect a feed-in premium and the TSO finances their purchase cost by a surcharge.

For installations with a domain concession granted before 1 July 2007, the TSO is also obliged to pay one-third of the costs of the submarine cable up to a maximum 25 million EUR (27 million USD) for a project of 216 MW or more. For smaller projects, the TSO's payment obligation is reduced proportionally. This obligation also applies for installations with a domain concession granted after 1 July 2007. These installations granted after 1 July 2007, were granted authorization not to get connected to an installation for the transmission of electricity within the marine areas, for which the minimum price is increased by 12 EUR/MWh (13 USD/MWh).

There are also tax incentives for investments in wind power. These are tax-deductible for companies. The tax deduction rate lies between 13.5% and 20.5% depending on the average development of the consumer price index.

Regarding land-based wind, the Flemish Region reformed its green certificate system in 2012, cutting the duration and reducing support levels. Support levels are reviewed annually to ensure consistency with the targeted rates of return. The Brussels-Capital Region also reformed its system in 2012, introducing a stabilization mechanism to avoid cost and volume overruns.

The Walloon Region followed with an overhaul of its system in the summer of 2014, capping the volume of green certificates for the following years and adopting a new formula for calculating the number of the certificates on the basis of power generation and the evolution in electricity prices, $CO_2$ performance of electricity generation, and investment costs. The Walloon system is reviewed every two years.

The targeted return on investment differs by region and technology. In the Flemish Region, the system aims at a guaranteed return on investment of 8% for wind. In the Walloon Region, the targeted rates are 7%

**Table 1. Key National Statistics 2015: Belgium**

| | |
|---|---|
| Total (net) installed wind capacity | 2,229 MW |
| New wind capacity installed | 270 MW |
| Total electrical output from wind | 5.5 TWh |
| Wind-generated electricity as a % of national electric demand | 6.7% |
| Average national capacity factor | 30.3% |
| Target: | 13% of renewables by 2020 in final gross energy consumption |

Source: Energy Observatorium, Federal Public Service of Economy

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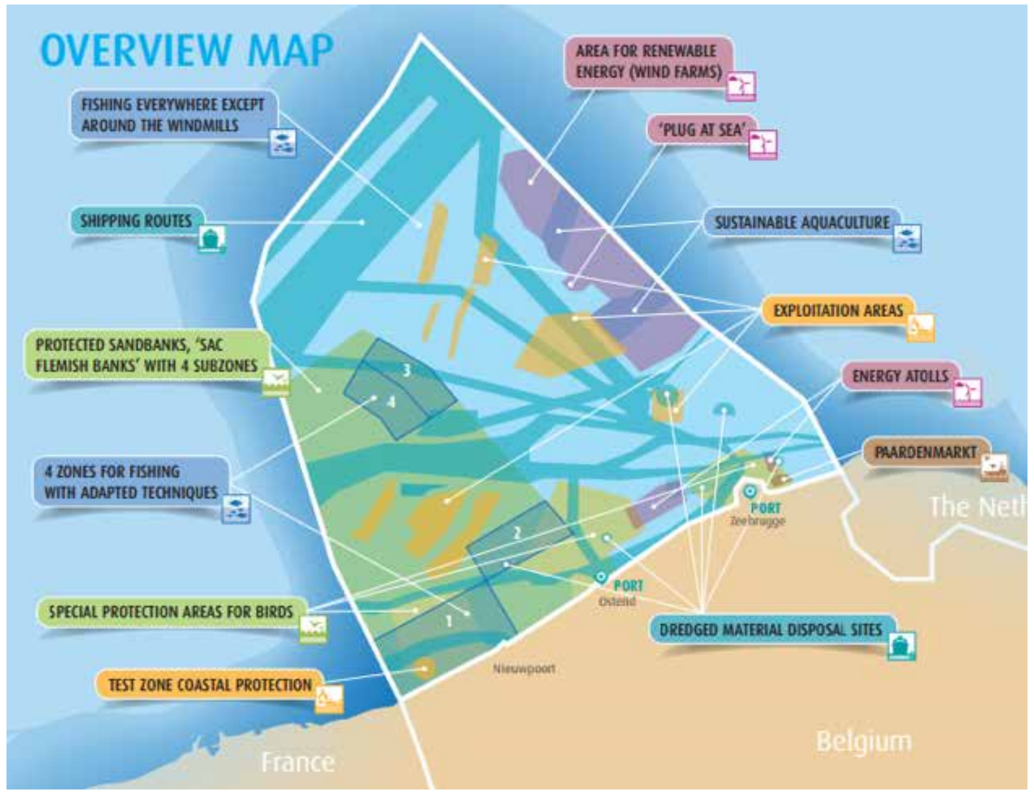

Figure 1. Overview map of the Belgian part of the North Sea (Source: Belgian Federal Public Service Health, Food Chain Safety and Environment)

**Table 2. Evolution of Total Capacity and Production of Wind Energy in Belgium**

| Year | Offshore | | Land-based | | Total wind generation (GWh) | Total electricity generation (GWh) | Electrical generation met by wind (%) |
|---|---|---|---|---|---|---|---|
| | Capacity (MW) | Generation (GWh) | Capacity (MW) | Generation (GWh) | | | |
| 2000 | 0 | 0 | 14 | 16 | 16 | 84,012 | 0.02 |
| 2001 | 0 | 0 | 26 | 37 | 37 | 79,821 | 0.05 |
| 2002 | 0 | 0 | 31 | 57 | 57 | 82,069 | 0.07 |
| 2003 | 0 | 0 | 67 | 88 | 88 | 84,643 | 0.10 |
| 2004 | 0 | 0 | 96 | 142 | 142 | 85,025 | 0.17 |
| 2005 | 0 | 0 | 167 | 227 | 227 | 87,025 | 0.26 |
| 2006 | 0 | 0 | 212 | 366 | 366 | 85,617 | 0.43 |
| 2007 | 0 | 0 | 276 | 491 | 491 | 88,822 | 0.55 |
| 2008 | 0 | 0 | 324 | 637 | 637 | 84,930 | 0.75 |
| 2009 | 32 | 82 | 577 | 914 | 996 | 91,235 | 1.09 |
| 2010 | 197 | 190 | 716 | 1,102 | 1,292 | 95,189 | 1.36 |
| 2011 | 197 | 709 | 873 | 1,603 | 2,312 | 90,241 | 2.56 |
| 2012 | 381 | 854 | 989 | 1,897 | 2,751 | 82,923 | 3.32 |
| 2013 | 708 | 1,540 | 1,084 | 2,147 | 3,687 | 83,526 | 4.41 |
| 2014 | 708 | 2,216 | 1,222 | 2,398 | 4,614 | 72,687 | 6.35 |
| 2015 | 712 | 2,613 | 1,517 | 2,855 | 5,468 | 68,138 | 8.03 |

(Source: Energy Observatorium, Federal Public Service of Economy)

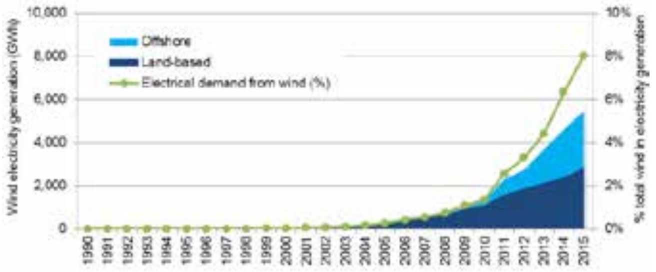

Figure 2. Production of electricity from wind (GWh) and percentage of wind in gross electricity generation (Source: Energy Observatorium, Federal Public Service of Economy)

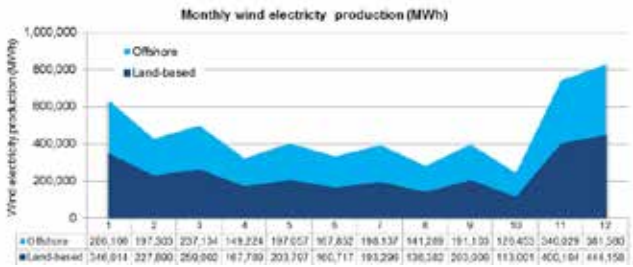

Figure 3. Monthly production data (MWh) for offshore and land-based wind in 2015 (Source: Energy Observatorium, Federal Public Service of Economy)

**Table 3. Green Certificate Systems in Belgium**

| | Federal level | Flemish Region (land-based) | Walloon Region (land-based) | Brussels-Capital Region (land-based) |
|---|---|---|---|---|
| Based on | MWh generated | MWh generated | $CO_2$ avoided | $CO_2$ avoided |
| Quota 2014 (%) | - | 15.5 | 23.1 | 3.8 |
| Quota 2017 (%) | - | 19 | 33.0 | 5.8 |
| Quota 2020 (%) | - | 20.5 | 37.9 | 8.0 |
| Minimum price/ certificate; Purchasing entity | 90 to 107 EUR (98 to 116 USD) or LCOE (max. 138 EUR (150 USD) (see section 2.3) | Price varies by technology; DSOs | 65 EUR (72 USD); TSO | - |
| Duration in years | 20 | 15 | 15 | 10 |
| Fine, certificate not submitted | - | 100 EUR (109 USD) | 100 EUR (109 USD) | 100 EUR (109 USD) |
| Certificates accepted | No tradability | Flemish only | Walloon only | Brussels-Capital and Walloon |

for wind. In the Brussels-Capital Region, a payback time of seven years is targeted, roughly equaling a return of 10% per year (Table 3).

### 2.4 Issues affecting growth

The federal and regional authorities need to address the perceived lack of certainty for investors in wind electricity generation. The generous green certificates systems, together with a drop in deployment costs, led to overcompensation, excess demand for installations, and increased distribution tariffs for electricity. Consequently, the support levels were reduced several times by the different regions and at the federal level between 2012 and 2015. The perception of regulatory risk created these changes had a direct impact on capital financing costs and the costs of project development. In 2015, the different entities have controlled the costs and focused on ensuring a given rate of return on capacity investment, instead of simply compensating for volumes generated. This created clear, stable, and predictable support systems.

Work to remove barriers to new wind energy projects also continues. Such barriers include spatial planning limitations (i.e. linked to military, aeronautical, or traffic related restrictions) and lengthy permitting procedures. The federal administration has created a "one-stop-shop" aimed at simplifying and speeding up the license procedures. Lengthy legal procedures also affect the sector. For example, cases where local communities appealed against the construction of wind energy facilities have taken years to resolve. Potentially, such legal cases could be avoided by involving the local communities more closely at the project planning stage and by offering them the opportunity to take part in investments through cooperatives.

In general, the main issue affecting growth for wind is the number of judicial appeals filed at the State Council, which has severely hindered the development of land-based wind farms both in the Flemish and

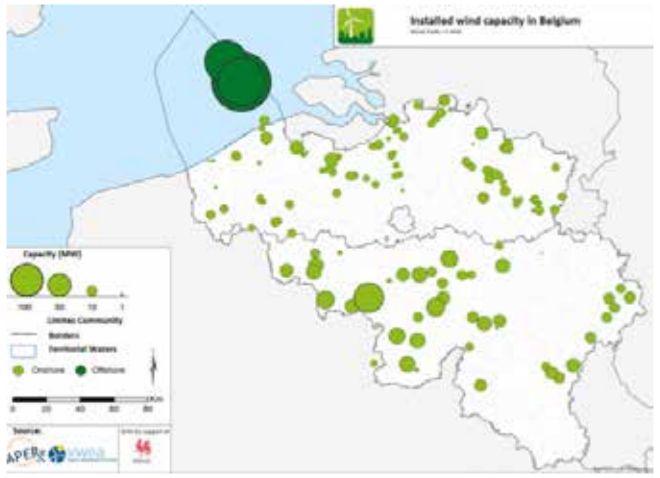

Figure 4. Wind capacity installed in Belgium as of January 2015 (Wind parks > 0.1 MW) (Source: APERe and VWEA)

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Figure 5. FLiDAR floating lidar system (Source: www.leosphere.com/products/floating/flidar-floating-buoy-lidar)

Wallonia regions. Belgium is not as abundantly endowed with wind energy potential as many other countries under current technologies. It has, however, relatively good resources for offshore wind. That is why under current technologies offshore wind has the most potential following the IEA in-depth review in 2015 [4].

## 3.0 Implementation

Figure 4 shows the capacity of wind energy installed in Belgium. Offshore wind parks are concentrated while land-based wind is quite dispersed around the country.

### 3.1 Economic impact

In addition to the many environmental benefits of wind energy such as $CO_2$ reduction and increased biodiversity, the wind sector creates excellent opportunities on the economic and industrial level and creates employment. Being active in this industry has also created opportunities for export. Besides building the wind parks, there is a need for building the grid infrastructure, grid connection, and the connections with neighboring countries. The impact on employment is huge: jobs are created in the design, construction, maintenance, and replacement of wind parks in addition to the permanent workforce, often in areas with few job opportunities. Realizing Belgium's total offshore wind potential in 2020 will create 20,000 person-years of employment during the building and developing phase and 800 permanent jobs during exploitation phase of at least 20 years [3].

### 3.2 Industry status

Belgium has exceptional manufacturing companies such as Xant, which produces small and medium size wind turbines; component suppliers such as ZF Wind Power, CG Power, Sky Man, Monitoring Solutions; and operators such as OWI-lab, VJI, Laborelec, and most of the universities.

#### 3.2.1 The Lidar project

The Lidar project has been developed by global energy consultant 3E and Offshore and Wind Assistance NV (OWA). The FLiDAR floating lidar is an offshore meteorological station designed for marine renewable energy technologies. FLiDAR can measure wind potential up to 200 m above mean sea level with an accuracy equivalent to the performance of land-based measurement devices. A full-size prototype of the floating lidar offshore resource assessment system was tested in 2011 at 15 km off the Belgian coast. This was the first successful trial of a floating lidar device in real offshore conditions in the North Sea (Figure 5).

#### 3.2.2 Xant

Xant manufactures robust, medium-size wind turbines for off-grid, hybrid, and remote applications. Their goal is to bring tailored wind turbine technology to community wind projects that enable farmers, businesses, schools, and villages to reduce energy costs wherever they live and work. Xant builds turbines with extremely high reliability, simple logistics, and increased yield at low winds.

#### 3.2.3 Estinnes wind farm

WindVision, Enerco, Eneco, and Elia have finalized the "R2 downward wind" pilot project. The pilot project investigates the technical capability of wind farms to regulate their power infeed in real-time to balance the active power in the grid. This will facilitate the further integration of renewables in the grid and as such contribute to the fulfilment of the European 2020 energy and climate targets.

Within the framework of this project, the Enercon turbines in the Estinnes wind park contributed to the delivery of secondary control power to the Belgian grid for a period of about two months. They did this by continuously changing the active power output of the turbines according to a set-point defined by Elia. Eneco was responsible for balancing contributions from the wind park and offered available secondary control capacity on the wind park to Elia. The Estinnes windfarm features the Enercon 7.5-MW (E-126) wind turbines with a rotor diameter of 126 m and a hub-height of 135 m.

#### 3.2.4 Belwind I – windfarm (165 MW + 6 MW Haliade 150 prototype)

The Belwind wind farm is 46 km off the coast of Zeebrugge on the Bligh Bank. It is the furthest wind farm offshore and therefore cannot be seen from land. It is the first EU far-shore offshore wind farm and has extensive R&D measurements partnership with OWI-lab.

The Heliade 150, the first Alstom offshore direct-drive wind turbine, is rated at 6 MW. Thanks to its 150-m rotor, with blades stretching 73.5 m, the turbine is more efficient. It yields 15% more than existing offshore turbines, enabling it to supply power to the equivalent of about 5,000 households. This new-generation wind turbine operates without a gearbox, using direct drive. Lastly, the Haliade 150 features Alstom's PURE TORQUE® design, which protects the generator by diverting unwanted mechanical stress towards the tower, thereby optimizing performance.

#### 3.2.5 Highwind floating factory of the future

The Innovation 1 vessel, which costs 220 million EUR (239 million USD), is used by GO Infra Sea Solutions. It is a joint venture with the German group Hochtief. Rather than placing parts one at a time, the Innovation 1 vessel can place a wind turbine in one piece: foundation, tower, and blades. This translates to enormous savings during installation. Moreover, the vessel can operate in heavier weather than the current vessels and at a depth of 50 m. With this floating factory of the future, Belgium will be able to place wind turbines throughout the year.

### 3.3 Operational details

The rated capacity of installed turbines has increased quite sharply for offshore and land-based wind. Capacity factor of new installations has also fluctuated each year as shown in Table 4 (Source: Energy Observatorium, Federal Public Service of Economy).

Table 5 shows the operational status of all the offshore wind parks in Belgium, while the same data is unavailable for land-based wind parks

## 4.0 R, D&D Activities

Much of the R&D efforts in the private sector are confidential. In the public sector, we have a large research community working in the wind energy area such as Universiteit Gent, Katholieke Universiteit Leuven, ULB, Université Mons, Université de Liège, Sirris, and Laborelec.

### 4.1 National R, D&D efforts

On a Belgian level, we have put forward via the Steering Group of the SET-Plan in 2015 several key technologies that Belgium wants to invest in for the future. Offshore and land-based wind are key areas selected by Belgium for the SET-Plan. Concerning land-based wind, investments in R, D&D are highly volatile. Indeed, the support mechanisms for research in the energy sector are on an equal footing with other areas of research following a principle of competition clearly defined and established.

**Table 4: Capacity Factors for Land-Based and Offshore Wind**

| Year | Capacity Factor (%) | |
|---|---|---|
| | Land-based | Offshore |
| 1990 | 15.98 | 0.00 |
| 1991 | 18.26 | 0.00 |
| 1992 | 20.55 | 0.00 |
| 1993 | 18.26 | 0.00 |
| 1994 | 20.55 | 0.00 |
| 1995 | 20.55 | 0.00 |
| 1996 | 18.26 | 0.00 |
| 1997 | 18.26 | 0.00 |
| 1998 | 20.93 | 0.00 |
| 1999 | 14.84 | 0.00 |
| 2000 | 13.05 | 0.00 |
| 2001 | 16.25 | 0.00 |
| 2002 | 20.99 | 0.00 |
| 2003 | 14.99 | 0.00 |
| 2004 | 16.98 | 0.00 |
| 2005 | 15.52 | 0.00 |
| 2006 | 19.71 | 0.00 |
| 2007 | 20.31 | 0.00 |
| 2008 | 22.44 | 0.00 |
| 2009 | 18.10 | 29.70 |
| 2010 | 17.59 | 11.01 |
| 2011 | 20.97 | 41.20 |
| 2012 | 21.89 | 25.59 |
| 2013 | 21.61 | 24.84 |
| 2014 | 22.40 | 35.75 |
| 2015 | 21.49 | 41.90 |

The R&D budget for wind for 2012 amounted to 2.795 million EUR (3.041 USD), in 2013 to 2.385 million EUR (2.595 million USD) and in 2014 to 4.009 million EUR (4.460 million USD). But as explained, this can vary a lot per year depending on the projects approved. Nonetheless, with some research projects (like GREDOR or SmartWater in the Walloon Region for example), Belgium is developing services that will ease the future integration of a larger share of wind energy by modernizing the electric grid and offering capacity of clearly tailored storage. In addition, the Department of Energy and Sustainable Building of the Walloon Region encourages the implementation of research projects in the energy sector by proposing annual budgets (approximately 1 million EUR (1.1 million USD) that can be also dedicated to projects in the wind energy field. However, it should be noted that Wallonia has no suitable industry to produce wind turbines and that expertise is built more on associated services that may benefit to the wind sector directly or indirectly.

The Flemish Region supports R, D&D in offshore and land-based wind via several projects. An important one is the co-financing of the state-of-the-art project OWI-lab (www.owi-lab.be/). The OWI-Lab was initiated by several leading companies in the Belgian wind energy sector (3E, GeoSea-DEME, ZF Wind Power (formerly Hansen Transmissions), and CG Power Systems) in close collaboration with the Agoria Renewable Energy Club and GENERATIES, the industrial innovation platform for renewable energy technologies in the Flemish Region. Vrije Universiteit Brussel (VUB) is responsible for the academic research part in this project in close collaboration with the other local universities.

In 2015, several projects have come to an end within a large scope of domains related to wind energy. These projects are the following:

- FONDEOLE – 300,125 EUR (326,536 USD). The project proposed to develop a new structure to anchor offshore wind turbines. The project has demonstrated a noticeable decrease in the amount of steel required for the installation of deep foundations for offshore wind turbines and responded more reliably to field constraints. Installation costs should, therefore, be reduced and mainly controlled.
- EOSIM – 197,970 EUR (215,391 USD). Offshore Wind SIMulation (EOSIM) is a tool for the management and planning of offshore wind projects developed to meet industrial problems encountered during the construction and assembly of these structures.
- FEDO – 563,720 EUR (613,327 USD). The optimization of electrical machines and their control has recently become (again) an extremely promising subject, because electricity and electrical machinery are key technologies for a low-carbon society. The project objective was to develop an open source software tool to complete the design, simulation, and optimization of electric drives. This flexible environment will couple the existing free software for electromechanical analysis/thermal/acoustic coupling with the control electronics and optimization.
- WINDIAG – 195,500 EUR (212,704 USD). The project designed an online tool that helps line fault diagnosis and helps with predictive maintenance of electrical actuators for the orientation of the wind turbine blades.

**Table 5. Status of Offshore Projects in Belgium (Source: Federal Public Service of Economy)**

| Project Name | Status | Number of turbines | Total Power |
|---|---|---|---|
| C-Power | Fully operational since September 2013<br>Build in 3 phases –<br>• Phase 1 with 6 x 5-MW turbines (started in 2009)<br>• Phase 2 with 30 x 6.15-MW turbines (operational in October 2012)<br>• Phase 3 with 18 x 6.15-MW turbines (started September 2013)<br>Bathymetry 12 to27.5 m<br>Distance to shore: 30 km<br>Foundations Phase 1: Gravity Based<br>Foundations Phase 2 and 3: Jacket | 54 | 325.2 MW<br>300,000 families<br>1,050 GWh/j |
| Northwind (formerly Eldepasco) | Operational since May 2014<br>Turbines: 3 MW<br>Bathymetry: 16 to 29 m<br>Distance to shore: 37 km<br>Foundations: Monopile | 72 | 216 MW<br>250,000 families<br>8,75 GWh/j |
| Belwind | 55 turbines operational since December 2010 and one 6-MW turbine since 2014<br>Bathymetry: 18 to 31 m<br>Distance to shore: 46 km to 52 km<br>Foundations: Monopile | 56 | 171 MW<br>160,000 families<br>550 GWh/j |
| Nobelwind | Planning 2017<br>Concession and environmental permit granted<br>Bathymetry: 25 to 42 m<br>Distance to shore: 46 km to 52 km<br>Foundations: Monopile | 50 | 165 MW<br>194,000 families<br>679 GWh/j |
| Rentel | Planning 2017–2018<br>Concession and environmental permit granted | 48 | 288–312 MW |
| Norther/North Sea Power | Planning 2016–2017<br>Concession and environmental permit granted<br>Bathymetry: 14 to 30 m<br>Distance until 21 km to shore | 30-60 | 300–350 MW<br>300,000 families |
| Seastar | Planning 2017-2018<br>Concession and environmental permit granted | 41 | 246 MW |
| Mermaid | Planning 2018<br>Concession granted | 27-41 | 232–266 MW |
| Northwester 2 | Planning 2018<br>Concession granted | 22-32 | 217–224 MW |
| Mermaid Wave | Concession granted | 4 batteries | 20-61 MW |

- D4WIND – 545,000 EUR (592,960). The project aimed to design, manufacture, and test a new type of vertical axis wind turbine.
- POWER – 3,513,854 EUR (3,823,073 USD). The project worked to improve reliability of wind turbines, optimize production, and improve power quality.

### 4.2 Collaborative research

In 2015, the Federal Public Service of Economy decided to become a member of the IEA Wind Technology Collaboration Programme because international collaboration is thought to be essential to accelerate the urgently needed investments in research and development in renewable energy, such as in wind. In 2015, Sirris, on behalf of Belgium, decided to participate in Task 19 Wind Energy in Cold Climates because there is a unique cold climate chamber in Belgium—the OWI-lab test facility (Figure 6).

OWI-lab focuses on offshore wind R&D. They made an investment of 5.5 million EUR (6.0 million USD) in state-of-the- art test and monitoring tools including:

- Large climatic test chamber (-60°C to +60°C; humidity)
- Floating lidar (FLiDAR)
- Offshore measurement systems
- R&D and innovation projects
- SMART operations & maintenance research

The Flemish Region participates in ERA-Net Cofund DemoWind for which the second call is now open (www.demowind.eu/pages/home-5.html). DemoWind is the Offshore Wind European Research Area Network (ERA-NET) Cofund, funded by the European Union's Horizon 2020 programme. DemoWind brings together European R&D funding organizations from six countries: Belgium, Denmark, Netherlands, Portugal, Spain, and the UK. DemoWind aims to support the development and demonstration of innovative technologies which can reduce the cost of offshore wind energy.

Figure 6. OWI-lab facilities (Source: www.owi-lab.be/)

The Walloon Region participates through research programs such as the New European Wind Atlas (NEWA) led under the 7th Framework Programme for research and development, Wallonia favors the emergence of quality projects rather than structural investments in clearly defined areas.

**The North Seas Countries' Offshore Grid Initiative (NSCOGI)**

On the 3 December 2010 a "Memorandum of Understanding" (MoU) was signed by ten countries and the European Commissioner for Energy. These ten countries include Belgium, Denmark, France, Ireland, Luxembourg, the Netherlands, Norway, Sweden, and the United Kingdom have committed themselves to develop an offshore network in the North Sea to secure the supply of electricity in the future and the necessary onshore connection. Belgium is the pioneer of this initiative and leads the work.

## 5.0 The Next Term

In 2016, 165 MW of offshore wind power will be under construction, at Nobelwind, formerly known as Belwind phase II. A minimum of 229 MW of land-based wind power: 150 MW in the Flemish Region and 79 MW in the Walloon Region will be installed. Further, the offshore wind parks Rentel, Norther, Seastar, Mermaid, and Northwester 2 are already fully approved by all planning bodies which accounts for another 1,283–1,428 MW offshore (before the end of 2019) and a minimum of 110 MW of land-based wind power.

**References:**

Opening photo: Six 5-MW C-Power wind turbines and two jackets for six 15-MW turbines (Source: C-Power)

[1] International Energy Agency (IEA) (2015a), Energy Balances of OECD Countries, www.iea.org/statistics/, OECD/IEA, Paris.

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# 20 Canada

## 1.0 Overview

In May of 2015, Canada surpassed the 10,000 MW threshold, and ended 2015 with just over 11.2 GW of installed wind capacity at 269 wind farms spread across ten provinces and two territories, placing it seventh in the world for installed capacity. Wind energy is estimated to have supplied approximately 5% of Canada's electricity demand.

In 2015, Canada ranked sixth globally in terms of new installed wind energy capacity with over 1,500 MW across five provinces. The 36 new projects commissioned comprised 743 wind turbines. The province of Ontario led the way with 871 MW of new capacity, followed by Quebec with 397 MW, Nova Scotia with 185.5 MW, and the remaining 52 MW split between Alberta and Saskatchewan.

Twenty three of the 36 new wind energy projects included significant ownership stakes by First Nations, municipal corporations, or local farmers—an increase from the 15 projects in 2014 that were similarly owned. This demonstrates the effectiveness of the tender and feed-in tariff (FIT) programs that target ownership by these stakeholders.

A trend away from FIT programs continued with Nova Scotia announcing the closure of its community feed-in tariff (COMFIT) program in August, following a review that found the program exceeded expectations and that no new projects were required in order to meet electricity demand. Alternately, calls for wind project tenders were initiated in Ontario for 300 MW of additional wind energy capacity and announcements for future procurement of wind energy in Alberta and Saskatchewan were also made.

The request for proposal (RFP) process has shown the continued cost competitiveness of wind energy with Quebec's announcement of successful bidders to its call for tenders for 450 MW of new wind capacity. Through this process, Hydro-Québec selected three projects totaling 446.4 MW, at an average price of 0.063 CAD/kWh (0.042 EUR/kWh; 0.046 USD/kWh). Taking into account electricity transmission costs, the total average price was 0.076 CAD/kWh (0.051 EUR/kWh; 0.055 USD/kWh).

## 2.0 National Objectives and Progress

### 2.1 National targets

Although there are no national wind energy deployment targets, the government of Canada announced plans in May 2015 to reduce the nation's greenhouse gas emissions (GHGs) by 30% below 2005 levels by 2030. Prime Minister Justin Trudeau opened dialogue with the Canadian provincial and territorial leaders at a First Minister's meeting in November 2015 where they discussed climate change and Canada's approach to the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21). At the Paris COP21, the newly elected government reaffirmed Canada's GHG reduction commitment and its commitment to continue Canada's role in addressing climate change. Wind energy will have a role in meeting these commitments.

With regards to provincial activities, in its *2013 Long-Term Energy Plan* the province of Ontario's Ministry of Energy forecasted that wind energy is expected to provide 15% of Ontario's supply mix in 2025, up from 6% in 2013. Overall, this will contribute to the 20,000 MW of renewable energy that is expected to be online by 2025, representing about half of Ontario's supply mix.

In western Canada, the provinces of Alberta and Saskatchewan are both committing to substantial increases in the proportion of electricity generation from renewable sources. In November, Alberta announced its plans to reduce GHGs from coal-fired electricity to zero by 2030 through the retirement of coal generation—replacing it with at least two-thirds renewable energy generation. Under the plan renewable energy will power up to 30% of Alberta's electricity grid by 2030.

Saskatchewan announced its plan to supply 50% of its electricity capacity from renewable sources by 2030. The province presently has 220 MW of wind capacity and is moving ahead with three new wind power projects already approved or in development, adding an additional 207 MW by 2020. To meet the provincial target, SaskPower, the provincial electricity utility is expected to move forward with procurement of another 100 MW of wind generation in 2016, and up to 1,600 MW between 2019 and 2030.

On the Atlantic coast, the province of Nova Scotia set aggressive goals for renewable energy. In 2010, Nova Scotia passed a law requiring 25% of the province's power to come from renewables by 2015 and 40% by 2020. It exceeded its first goal by generating 26.6% of its electricity from renewable sources in 2015.

Also on the Atlantic coast, the province of New Brunswick (NB) set its direction under their *Climate Change Action Plan 2014–2020*. The government of New Brunswick will require NB Power to source 40% of in-province electricity sales from renewable sources by 2020. The Plan sets a GHG emissions reduction target of 10% below 1990 levels by 2020 and 75–85% below 2001 levels by 2050.

### 2.2 Progress

In Ontario approximately 871 MW of wind energy capacity was installed in 2015, leading all other provinces. Transmission-connected wind projects produced 9.0 TWh in 2015, approximately 6% of Ontario's electricity output. At the end of the year Ontario had approximately 4.4 GW of wind power online.

In Quebec, 397 MW of new wind capacity was commissioned in 2015. The 200-MW Phase 2 of EDF EN Canada's 350-MW Rivière-du-Moulin wind project in Quebec was commissioned in November. With the completion of this phase, the project is the largest multi-phase wind energy facility in Canada.

In Nova Scotia, wind energy now provides close to 10% of the electricity supply. In 2015, 18 new wind projects were commissioned representing an additional 185.5 MW of wind capacity, and 2015 saw the commissioning of the largest wind project in Nova Scotia, the 102-MW South Canoe Wind Farm, jointly owned by Oxford Frozen Foods, Minas Basin Pulp and Power, and Nova Scotia Power Inc.

In Alberta and Saskatchewan, only one project was completed in each province in 2015, representing just over 50 MW of new capacity across both jurisdictions. However, both provinces made significant commitments towards growing their contributions of renewable sources of power, particularly wind energy, with goals to significantly reduce their reliance on coal for electricity generation.

### 2.3 National incentive programs

The government of Canada, through the Wind Power Production Incentive (WPPI) and the ecoENERGY for Renewable Power (ecoERP) programs, committed about 1.4 billion CAD (0.93 billion EUR; 1.01 billion USD) toward wind energy projects. A total of 89 projects, representing 4,442 MW of installed capacity, qualified for an incentive of 0.01 CAD/kWh (0.007 EUR/kWh; 0.007 USD/kWh) for the first ten years of operation, over and above the price paid through PPAs. The programs closed to new projects on 31 March 2011 with the WPPI program incentive ending in fiscal year 2016–2017, and the ecoERP incentive ending in fiscal year 2020–2021.

The ecoENERGY for Aboriginal and Northern Communities Program 2011–2016 (EANCP) focuses exclusively on providing funding support to Aboriginal and northern communities for renewable energy projects with the objective of reducing GHG emissions arising from electricity and heat generation.

Provinces across Canada continue to offer a range of policies for renewable power including wind. Ontario developed a competitive Large Renewable Procurement (LRP) process for projects over 500 kW to replace the former FIT program. The FIT program remains in place for projects less than 500 kW. The first round of procurement (LRP I) targets 300 MW of new wind capacity. The Ontario Power Authority posted the final call for the LRP I Request for Proposal in March 2015.

**Table 1. Key National Statistics 2015: Canada**

| | |
|---|---|
| Total (net) installed wind capacity | 11,205 MW |
| New wind capacity installed | 1,506 MW |
| Total electrical output from wind | ***28.5 TWh*** |
| Wind-generated electricity as a % of national electric demand | ***5.0%*** |
| Average national capacity factor | ***31%*** |

***Bold italic*** indicates estimates

| Table 2. Statistics for New Wind Farms Commissioned in 2015 in Canada | |
|---|---|
| Smallest wind farm | 1.4 MW—Fitzpatrick's Mountain, Nova Scotia |
| Largest wind farm | 270 MW—K2 Wind Power Facility, Ontario |
| Provinces with new wind farms | Alberta, Nova Scotia, Ontario, Quebec, Saskatchewan |
| Turbine manufacturers | Acciona, Enercon, GE, Senvion, Siemens, Vestas |
| Turbine sizes (range) | 1.4–3.0 MW |
| Average turbine size | 2 MW |

In Nova Scotia, the provincial government passed Bill No. 1: The Electricity Reform Act in December 2013, described as the "Renewable to Retail" initiative. In consultation with interested stakeholders, Nova Scotia Power developed a framework to enable competitive renewable electricity supply to retail customers, in accordance with the provisions of the Act. The aim is to open the electricity market to local investment opportunities. Under the proposed plan, licensed suppliers will be allowed to sell locally generated, renewable, low-impact electricity directly to end users. The process to establish distribution tariffs before opening the market is now underway with the final proposed tariff regime to be brought to the NS Utility and Review Board in 2016.

Also in Nova Scotia, the COMFIT program exceeded expectations, having awarded 89 approvals totaling 200 MW of additional wind capacity since the program began in 2011—twice its original target. The program no longer accepts applications for wind projects larger than 500 kW and limits the number of approvals per organization or private partnership. The COMFIT was designed to promote community-owned projects that are connected at the distribution level.

In Quebec, Hydro-Québec Distribution issued a call for tenders for 450 MW of wind power to be delivered in 2016 and 2017. The energy price was capped at 0.09 CAD/kWh (0.060 EUR/kWh; 0.065 USD/kWh). Hydro-Québec announced that it had selected three projects totaling 446.4 MW. The utility will pay an average 0.063 CAD/kWh (0.042 EUR/kWh; 0.046 USD/kWh) for the energy, and calculates additional costs for transmission and to connect the facilities will result in a total average price of 0.076 CAD/kWh (0.050 EUR/kWh; 0.055 USD/kWh).

### 2.4 Issues affecting growth

The Canadian Wind Energy Association (CanWEA) identifies low load growth as one of the main issues affecting the growth of the wind energy sector in Canada. The focus for many jurisdictions will be new markets—electrification of transportation and non-traditional sectors including export of Renewable Portfolio Standard (RPS) eligible power. In the medium term, the impact of the national and provincial policies to address GHG emission reduction targets may augment the demand for wind energy.

## 3.0 Implementation

### 3.1 Economic impact

Wind projects contribute millions to local communities in the form of job creation, new tax revenues, lease payments, and royalty payments. Investments are made during construction, creating local jobs and use of local resources. The 270-MW K2 Wind Power Project in Goderich, Ontario, owned by Pattern Energy, Samsung Renewable Energy, and Capital Power Corporation, was commissioned in 2015. The company reports that it will contribute an estimated 450,000 CAD in property taxes (299,250 EUR and 325,350 USD). Additionally, an average of 300 workers were on-site during project construction and approximately 20 full-time employees operate and maintain the facility.

The K2 project utilized blades manufactured in Tillsonburg, Ontario and towers manufactured in Windsor, Ontario with Ontario-made steel. Lastly, the company reports that it will contribute 15 million CAD (10 million EUR, 11 million USD) over 20 years to support community initiatives in the Township. K2 Wind is also providing an annual Community Renewable Energy Benefit payment to non-participating landowners living within one kilometer of turbines.

CanWEA estimates that in the province of Quebec alone, the wind energy industry has created over 5,000 jobs and generated 10 billion CAD (6.7 billion EUR; 7.2 billion USD) of investments over the past decade. The wind industry now contributes 500 million CAD (332 million EUR; 362 million USD) to Quebec's gross domestic product every year. The wind energy sector in Quebec has benefited from a ten-year period of predictable and integrated approaches of successive governments. For example, more than 80% of construction costs for the 211.5-MW Gros Morne wind farm in Quebec were spent in the administrative region of Gaspésie-Îles-de-la-Madeleine and the MRC Matane.

### 3.2 Industry status

3.2.1 Ownership

In Canada, wind farms are typically owned by independent power producers (IPPs), utilities, or income funds. However, in the last decade the provinces of Nova Scotia, Ontario, and Quebec have introduced policies to encourage local, community, and First Nations ownership. In 2015, wind energy developers commissioned 1,506 MW of new capacity from 36 projects, 23 of which involved Aboriginal Peoples, municipalities, or locally owned cooperatives or corporations, further demonstrating the opportunities for diverse ownership structures in Canada.

3.2.2 Manufacturing

Canada continues to attract wind power equipment manufacturers as well as component level suppliers and manufacturers. The country's manufacturing capacity is primarily based in Ontario and Quebec. In August 2014, the provincial government in Quebec established a working group to examine the required conditions for the continued development of the province's wind energy industry and associated manufacturing. The working group published its report in February 2015 [1].

### 3.3 Operational details

In 2015, Canada added 1,506 MW of new wind capacity in 36 projects in Alberta, Saskatchewan, Ontario, Quebec, and Nova Scotia. This includes:

- 871 MW in Ontario (for a total of 4,361 MW)
- 397 MW in Quebec (for a total of 3,262 MW) including the largest multi-phase project commissioned in Canada to date—the 350 MW wind farm in Riviere du Moulin
- 185.5 MW in Nova Scotia (for a total of 552 MW) including one of the largest municipal-owned wind projects in Canada, the Sable Wind Farm (14 MW).

These projects were supplied with wind turbines from six wind turbine manufacturers: Siemens Canada Limited led installations with close to 50%, followed by Senvion Canada Inc., GE Renewable Energy, Enercon, Acciona Wind Energy Canada, and Vestas Canada.

Canada had several installed capacity milestones in 2015—nationally Canada surpassed 10 GW, Ontario surpassed 4 GW, Quebec surpassed 3 GW, and the Atlantic Region, led by Nova Scotia, surpassed 1 GW of installed capacity.

### 3.4 Wind energy costs

The PPAs signed in 2014 show that the cost of electricity generated by wind continues to drop. Most recently these low prices have emerged in distinct markets in Canada—Quebec and Alberta. In their *2014 Long Term Outlook*, the Alberta Electric System Operator published data regarding the relative cost of seven different electricity sources on a CAD/MWh basis. In their analysis, wind was the second lowest cost source of electricity, slightly more expensive than combined-cycle natural gas-fired generating stations. In Quebec, the latest RFP contracts demonstrate the low cost of electricity generated by wind energy technologies with an average price of 63 CAD/MWh (42 EUR/MWh; 46 USD/MWh). Wind energy has proven itself to be a significant contributor to stable and low electricity prices.

## 4.0 R, D&D Activities

### 4.1 National R, D&D efforts

The focus of Canada's wind energy R&D activities is the integration of wind energy technologies into the electric grid and reducing dependency on diesel for electricity production for off-grid remote applications. Natural Resources Canada (NRCan) is the primary federal government department engaged in wind energy R&D.

NRCan's CanmetENERGY collaborated with the Caribou Wind Park in New Brunswick to quantify the wind energy production loss due to icing and to characterize the wind resource during icing episodes. In addition to the typical wind energy and icing parameters, information was collected on cloud physics—specifically the liquid water content and median volume diameter. The data were used to validate a mesoscale icing model that is under development.

In 2013, the government of Canada announced more than 82 million CAD (55 million EUR; 59 million USD) through NRCan's ecoENERGY Innovation Initiative (ecoEII) to continue supporting clean and renewable energy initiatives and research. The following wind-related initiatives are among the 55 projects that received funding:

- Tugliq Energy Co. installed and is operating a 3-MW Enercon E-82 wind turbine at the Glencore Raglan mine in Nunavik, Northern Quebec as part of a wind-diesel-energy storage demonstration project. A flywheel, a Li-Ion battery, and hydrogen energy storage technologies are being demonstrated through the project. The government of Canada initially contributed 720,000 CAD (478,800 EUR; 520,560 USD) to the 2 million CAD (1.3 million EUR; 1.5 million USD) Front End Engineering and Design study for this project. The total value of the demonstration project is approximately 18.98 million CAD (12.62 million EUR; 13.72 million USD) and is being supported by the government of Canada (7.8 million CAD (5.2 million EUR; 5.6 million USD)) and the Quebec government under its Plan Nord (6.5 million CAD (4.3 million EUR; 4.7 million USD)).
- CanWEA is the lead on the Pan-Canadian Wind Integration Study to evaluate the technical aspects and operational tools needed for high wind energy grid penetration on a national basis. The study will match time series modeled wind energy production data with electricity demand data, and evaluate how different wind penetration levels influence the rest of the electricity grid with specific considerations to system operations and reliability. The interconnected Canadian bulk power transmission system, including information on the United States transmission interconnections with Canada, will be modelled to conduct the study. The government of Canada contributed 1.8 million CAD (1.2 million EUR; 1.3 million USD) to this 2.7 million CAD (1.8 million EUR; 2.0 million USD) study.
- An assessment of GTRenergy Ltd.'s Virtual Blade Wind Power configuration of turbine blades to achieve increases in energy production is being supported. The government of Canada contributed 600,000 CAD (399,000 EUR; 433,800 USD) to this study, which has a total project cost of 1.1 million CAD (0.7 million EUR; 0.8 million USD).

In 2015, Health Canada researchers began to publish detailed results from their epidemiological study on noise and health impacts of wind turbines. A summary of results was released in November 2014. The study concluded that there is no evidence of a causal relationship between exposure to wind turbine noise and self-reported medical illnesses and health conditions, although it did identify a relationship with annoyance [2]. The first journal article, entitled *An assessment of quality of life using the WHOQOL-BREF among participants living in the vicinity of wind turbines*, was published in the October 2015 edition of the journal *Environmental Research*. Additional publications will be released in 2016 covering topics such as sleep, noise, and annoyance.

In April 2015 the Council of Canadian Academies released a report on the health effects of wind turbine noise. The report, *Understanding the Evidence: Wind Turbine Noise*, was prepared by a ten-member expert panel that evaluated the most rigorous scientific evidence on the question of wind turbine noise and human health [3].

New Brunswick Power (NB Power) is leading a project called Powershift Atlantic, which was launched in 2010 as a part of the government of Canada's Clean Energy Fund. Although now complete, PowerShift Atlantic was a research and demonstration project focused on finding more effective ways to integrate wind energy into the electricity system. The project allowed NB Power to adjust client's appliances in homes and commercial buildings in order to optimize wind generation. The project was valued at approximately 32 million CAD (21 million EUR; 23 million USD), with 15.6 million CAD (10.4 million EUR; 11.3 million USD) coming from the government of Canada.

TechnoCentre éolien (TCE) is a center of expertise related to wind energy in cold climates and complex terrain, adaptation of technologies,

Figure 1. TechnoCentre éolien maintenance on 126-m met mast and two 2.05-MW Senvion MM92 CCV (Photo credit: TechnoCentre éolien)

and integration of Quebec businesses into wind industry supply chains. TCE owns an experimental cold climate wind energy site in Rivière-au-Renard where there are two Senvion MM92 CCV wind turbines, each with a capacity of 2.05 MW. See Figures 1 and 2.

In 2015 TCE completed various projects developing camera-based digital image analysis tools which enable the characterization of icing events, of ice itself, and the impact of both on electricity production. This expertise and research capabilities contributed to Senvion partnering with TCE to carry out a project to optimize the production of their wind turbines in icing conditions. This 1.2 million CAD (0.798 million EUR, 0.868 million USD) project was supported by a grant of from the Natural Sciences and Engineering Research Council of Canada (NSERC). In partnership with Sigma Energy Storage (SES), TCE has developed and optimized a load-following feature for Compressed Air Energy Storage (CAES). This project, funded by NSERC, was completed during 2015.

Figure 2. TechnoCentre éolien research wind farm 2.05-MW Senvion MM92 CCV; Eocycle Technologies EO-25/12 direct-drive, 25-kW wind turbine; 126-m met mast (Photo credit: TechnoCentre éolien)

The Wind Energy Institute of Canada (WEICan), located at North Cape, Prince Edward Island is a non-profit, independent research and testing institute. WEICan's Wind R&D Park was commissioned in April 2013, see Figure 3. The Wind Park features five 2-MW DeWind D9.2 wind turbines and a 1-MW/2-MWh battery energy storage system. As a national research facility, independent wind farm, and battery energy storage system operator with strong industry ties WEICan leads research in wind farm operation and utilization of energy storage. Current research areas include:

- Wind Energy Storage and Grid Integration—investigating the optimal utilization, both technically and financially, of their energy storage system. Recent demonstrations include regulation, time shifting, and displacement of traditional peak generation.
- Impact of Wakes and Escarpments on Wind Speed and Turbulence—in 2015 WEICan hosted researchers from the University of Western Ontario, York University, and Cornell University, at its R&D Wind Park to collect wind speed and turbulence data. Met masts and LIDAR units were strategically placed throughout the site and data was collected for several weeks to understand the impact of turbulence from the escarpment near four of their five turbines as well as the wake effects on wind turbine performance and longevity.

Figure 3. Wind Energy Institute of Canada (WEICan) R&D Wind Farm 2-MW DeWind D9.2 wind turbines (Photo credit: WEICan)

- Availability Data Using a Standard Format—under a CanWEA pilot benchmarking data project, several wind farms across Canada are implementing Generating Availability Data System (GADS) reporting, which allows comparison across the wind industry and with traditional electricity generators. WEICan is processing the initial data and providing statistics to data contributors of the project.
- Service Life Estimation—data from its SCADA and recently installed condition monitoring tools are being analyzed to identify trends in maintenance issues, assess changes in load conditions, identify underperformance and component wear, and map structural aging. Data from the availability study and the wakes and escarpment study will be combined with the SCADA and condition monitoring data to estimate turbine service life.

### 4.2 Collaborative research

Canada participates in the IEA Wind Task 19 Wind Energy in Cold Climates and Task 32 Wind LIDAR for Wind Energy Deployment, with TCE as the Canadian representative to both; and Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power, represented by Hydro-Québec. Canada also participates in the International Electrotechnical Commission (IEC) Technical Committee-88.

## 5.0 The Next Term

According to CanWEA, Canada's wind power industry is expected to add approximately 1,000 MW of new capacity in 2016 in Alberta, British Columbia, Ontario, and Quebec. Furthermore, additional procurements are expected over the medium term in Alberta, New Brunswick, Ontario, Quebec, and Saskatchewan.

**References:**

Opening photo: Vestas 1.65-MW V-82 turbines at Mohawk Point Wind Farm, Ontario (Photo credit: Jimmy Royer: Natural Resources Canada)

[1] http://mern.gouv.qc.ca/publications/energie/eolien/Rapport_Groupe_de_travail_eolien_fevrier_2015_FINAL.pdf

[2] www.hc-sc.gc.ca/ewh-semt/noise-bruit/turbine-eoliennes/summary-resume-eng.php

[3] www.scienceadvice.ca/en/assessments/completed/wind-turbine-noise.aspx

Author: Paul Dockrill, Thomas Levy, Natural Resources Canada, Canada.

# 21 CWEA

## 1.0 Overview

**China saw 30,753 MW of new wind power capacity installed in 2015, increasing the accumulated capacity to 145,362 MW. China continues to have the highest wind power capacity in the world. In the past year, 32,970 MW of wind capacity were integrated to the grid, increasing the grid-connected capacity to 129,000 MW, which accounted for 8.6% of installed power capacity nationwide.**

**In 2015, the average full-load-hour of wind power was 1,728 hours, a decrease of 172 hours compared to 2014. Wind power generation increased by 21.44%, amounting to 186.3 TWh, which accounted for 3.3% of total electricity generation (an increase of 0.52% compared to 2014).**

**Wind power remains the third largest generation source in China, following thermal electricity and hydroelectricity. Wind energy represented the fourth energy investment in 2015, with an investment of 75.98 billion CNY (10.8 billion EUR; 11.7 billion USD), accounting for 15.2% of total project construction investment nationwide.**

**In 2015, the Chinese government considered wind power development as an important tool to promote an energy revolution, adjust the energy structure, and promote national energy security. To achieve these results, the government issued a series of policies and regulations and adjusted feed-in tariffs (FIT) for land-based wind power.**

**The average wind curtailment rate was 15%, an increase of 7% compared to 2014. In 2015 the government took many measures to further resolve this problem. Also this year, the government set policies to promote the reform of the electric power trading system and improve market-based trading mechanisms.**

## 2.0 National Objectives and Progress

### 2.1 National targets

In 2016, the Chinese government drafted the *13th Five-Year Plan on Wind Power Development (2016-2020)*. In this plan, the cap on annual primary energy consumption is set at 4.8 billion metric tons of standard coal equivalent until 2020, and annual coal consumption will be held below 4.2 billion metric tons until 2020. The annual renewable energy consumption is set at 747 million metric tons of standard coal equivalent until 2020. To meet the government's target of having about 15% and 20% of non-fossil fuels in total primary energy consumption by 2020 and 2030, respectively, the National Energy Administration (NEA) identified management measures, such as renewables portfolio standards (RPS) and full protection of the renewable energy acquisition, which must be formulated and implemented.

The NEA also outlined the necessary decrease in the cost of wind generation to realize the goal of 250 GW of wind capacity at a price equal to that of thermal electricity by 2020. Yearly wind power generation in 2020 will be 460 TWh, which will account for 6.3% of all power generation.

### 2.2 Progress

By the end of 2015, China had installed 30,753 MW of new wind power capacity during the year (exclusive of Taiwan). This added capacity in China accounted for 48.8% of new global wind capacity for the year. The accumulated wind power capacity in China reached 145,362 MW, accounting for 33.6% of wind power capacity worldwide, maintaining the highest wind power installation in the world. Compared to 2014, new wind installations increased by 32.6%, and the accumulated installation increased by 26.8%, as shown in Figure 1. In 2015, wind power generation reached 186.3 TWh, accounting for 3.3% of electricity generation.

### 2.3 National incentive programs

In order to promote the healthy development of the wind power industry, the Chinese government released a series of policies and regulations in 2015 to direct the wind power market development, to promote wind power integration and consumption, and to adjust the supportive feed-in-tariff (FIT).

Wind power curtailment is still a serious problem in China, therefore the government formulated a series of policies to support wind power integration and consumption in 2015. The National Development and Reform Commission (NDRC) and NEA officially announced six supporting documents for the electric power system reform. The new policies stipulated that the two ministries should push the reform of the electric transmission and distribution price and expand the pilot to the whole country as soon as possible. It also announced that a relatively independent power dispatch and trading institution and a priority power purchase and generation system will be established to guarantee the priority generation and power grid access of clean energy.

In 2015, the NDRC announced the adjustment of the land-based FIT. Tariffs for Class I, II, and III wind source areas decreased by 0.02 CNY/kWh and 0.03CNY/kWh (0.0028 EUR; 0.0031 USD and 0.0042 EUR; 0.0046 USD) in 2016 and 2018 respectively. In 2016, the tariffs for the three classes are 0.47 CNY/kWh (0.067 EUR/kWh; 0.072 USD/kWh), 0.50 CNY/kWh (0.071 EUR/kWh; 0.077 USD/kWh) and 0.54 CNY/kWh (0.077 EUR/kWh; 0.083USD/kWh). In 2018, tariff is set to 0.44 CNY/kWh (0.062 EUR/kWh; 0.068 USD/kWh), 0.47 CNY/kWh (0.067 EUR/kWh; 0.072 USD/kWh) and 0.51 CNY/kWh (0.072 EUR/kWh; 0.079 USD/kWh).

Tariffs for Class IV areas decreased by 0.01 CNY and 0.02 CNY (0.0014 EUR; 0.0015 USD and 0.0028 EUR; 0.0031 USD) in 2016 and 2018 respectively. The Class IV tariff is 0.60 CNY/kWh (0.085 EUR/kWh; 0.092 USD/kWh) and 0.58 CNY/kWh (0.082 EUR/kWh; 0.089 USD/kWh) for those years. The new FIT came into force on 1 January 2016.

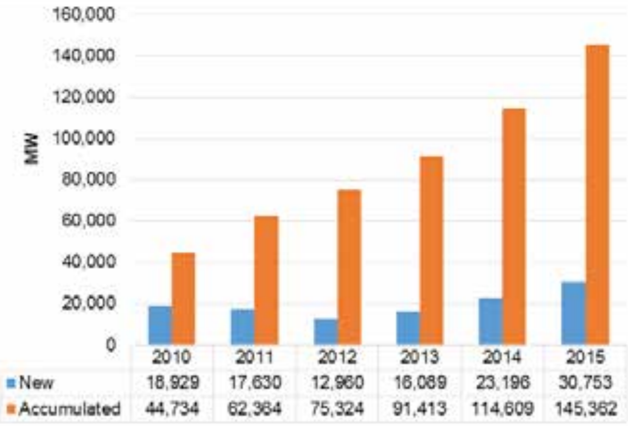

Figure 1. New and accumulated installed capacity from 2010–2015 in China

**Table 1. Key National Statistics 2015: China**

| | |
|---|---|
| Total (net) installed wind capacity | ***145,362 MW*** |
| New wind capacity installed | ***30,753 MW*** |
| Total electrical output from wind | 186.3 TWh |
| Wind-generated electricity as a % of national electric demand | 3.3% |
| Average national capacity factor | ***19.7%*** |
| Target: | By 2020: wind capacity of 250 GW; price of wind generation equals thermal electricity; annual wind generation of 460 TWh; and wind accounting for 6.3% of all electric generation. |

***Bold italic*** indicates estimates

**Table 2. Top 10 Developers of New Installation in China in 2015**

| No. | Developer | Capacity (MW) | Share |
|---|---|---|---|
| 1 | Guodian Group | 3,565.20 | 11.6% |
| 2 | Huaneng Group | 3,254.75 | 10.6% |
| 3 | China Power Investment Group | 2,464.00 | 8.0% |
| 4 | Huadian Group | 2,103.50 | 6.8% |
| 5 | Datang Group | 1,918.00 | 6.2% |
| 6 | CGN | 1,888.15 | 6.1% |
| 7 | Power China | 1,380.50 | 4.5% |
| 8 | Tianrun | 1,289.90 | 4.2% |
| 9 | Guohua | 994.80 | 3.2% |
| 10 | The Three Gorges | 875.10 | 2.8% |
|  | Others | 11,019.10 | 35.8% |
|  | **Total** | **30,753** | **100%** |

**Table 3. Top 10 Manufacturers of New Installation in China in 2015**

| No. | Manufacturer | Capacity (MW) | Share |
|---|---|---|---|
| 1 | Goldwind | 7,748.9 | 25.2% |
| 2 | United Power | 3,064.5 | 10.0% |
| 3 | Envision | 2,510.0 | 8.2% |
| 4 | Mingyang | 2,510.0 | 8.2% |
| 5 | CSIC Haizhuang | 2,092.0 | 6.8% |
| 6 | Shanghai Electric | 1,926.5 | 6.3% |
| 7 | XEMC-Wind | 1,510.0 | 4.9% |
| 8 | Dongfang Turbine | 1,388.0 | 4.5% |
| 9 | Windey | 1,260.0 | 4.1% |
| 10 | Sany | 951.0 | 3.1% |
|  | Others | 5,792.1 | 19% |
|  | **Total** | **30,753** | **100%** |

### 2.4 Issues affecting growth

Integration and consumption are still the significant problems limiting wind power development in China. Though wind generation increased by 21.44% in 2015, the average full-load-hour of wind power decreased by 172 hours compared to 2014. In contrast to the previous years, decrease in full load hours in 2015 was partly due to the circumstance that supply exceeds demand in power market. Wind curtailment was still the main restriction on wind power development.

## 3.0 Implementation

### 3.1 Economic impact

According to the sampling of domestic enterprises and considering the mean labor productivity of the manufacturing industry in China, currently about 15 jobs could be produced by every 1 MW of wind installation. Among this, 13 to14 jobs are produced by the manufacturing industry, and about 1.5 jobs are created by installation and maintenance, etc.

In China, wind jobs surged from 356,000 in 2013 to 502,400 in 2014. More than 70% of the jobs are in manufacturing. The government estimated that until 2020, more than one million people will be working in wind power industry.

### 3.2 Industry status

#### 3.2.1 Developers

In 2015, the top five developers in China were Guodian Group (3,565.2 MW), Huaneng Group (3,254.75 MW), China Power Investment Group (2,464 MW), Huadian Group (2,103.5 MW), and Datang Group (1,918 MW), which together accounted for 43.2% of new wind installation. The top ten developers accounted for 64.2% of new wind capacity, as shown in Table 2.

#### 3.2.2 Manufacturing industry

In 2015, the top five manufactures of new installation were Goldwind (7,748.9 MW), United Power (3,064.5 MW), Envision (2,510 MW), Mingyang (2,510 MW), and CSIC Haizhuang (2,092 MW), which together account for 58.3% of new wind installation. The top ten manufactures accounted for 81% of the new wind installation, as shown in Table 3. Compared to 2013, Goldwind and CSIC Haizhuang had the most significant increase, which is 74.8% and 82.9%, respectively.

### 3.3 Operational details

In 2015, a total of 16,740 new wind turbines were installed. This brought the national total to 92,981 operating turbines. At the provincial level, the five provinces with the most new installations were Xinjiang (6,583 MW), Inner Mongolia (3,355 MW), Yunnan (2,325 MW), Ningxia (2,230 MW), and Shanxi (1,705 MW), which together accounted for 53.3% of national new additions. The average full-load hours of operating wind farms was 1,728 hours, a decrease of 172 hours compared to 2014.

### 3.4 Wind energy costs

The development cost of a wind power project in 2014 was 8,619 CNY/kW (1,223.89 EUR/kW; 1,327 USD/kW), a decrease of 325 CNY (46.15 EUR; 50.05 USD) compared to 2013.

In 2015 the development cost of land-based wind energy was 0.32–0.47 CNY/kWh (0.04–0.06 EUR/ kWh; 0.05–0.07 USD/kWh) based on land-based wind power resources, construction conditions, and mainstream wind turbines technologies and wind farm operation levels. Under the current technology, without considering the cost of long-distance transmission, or the resource and environmental benefits of wind power, the cost of wind power is higher than that of coal-fired power by 0.20 CNY/kWh (0.028 EUR/kWh; 0.031 USD/kWh). If resources and environmental benefits are taken into consideration, the cost of wind power was nearly equal to that of coal-fired power generation.

## 4.0 R, D&D Activities

### 4.1 National R, D&D efforts

#### 4.1.1 Fundamental research

In 2015, the Ministry of Science and Technology of the People's Republic of China continued to support the High Technology Research and Development Plan (863 Plan), the Key Fundamental Technology Research and Development Plan (973 Plan), and the Science and Technology Support Research Project. Two projects were related to wind power, as follows:

1. Research and demonstration on the intelligent control of wind turbine and key technology of smart wind farm, focusing on intelligent control technology of wind turbines (12.79 million CNY; 1.81 million EUR; 1.97 million USD); intelligent monitoring and maintenance dispatching system for large scale wind farm (7.72 million CNY; 1.09 million EUR; 1.19 million USD); key technologies of intelligent operation and maintenance of large scale wind farm (6.09 million CNY; 0.86 million EUR; 0.94 million USD); and key technology of intelligent wind farm design optimization (10.7 million CNY; 1.52 million EUR; 1.65 million USD).

2. Research on wind turbine test technology, focusing on key technology and equipment development of offshore wind turbine test (27.72 million CNY; 3.94 million EUR; 4.27 million USD) and the transmission chain of large-scale wind turbine test technology (10.96 million CNY; 1.56 million EUR; 1.69 million USD).

The research projects above aim to solve important technical problems in wind energy. They will improve key technologies, promote the competitiveness of the industry, and provide technical support for the healthy and sustainable development of the wind industry in China.

#### 4.1.2 Applied research

In 2015, China added 360.5 MW of offshore wind power installations, increasing the cumulative capacity to 1,014.68 MW. All of these offshore projects provided valuable experience for development of offshore wind power in China. China has carried out a series of experiments regarding offshore wind power. For example, by comparing the numerical results with the experimental data, Goldwind carried out an investigation on the hydrodynamics of cylinders under different wave conditions to find out the influence of wave theories and approaches for hydrodynamic coefficients on the hydrodynamic loading. The relevant methods will be used for the hydrodynamic modeling of offshore wind turbines in the following research stage.

With the increase of wind power installation, wind farm management and O&M are playing an increasingly important role. In Task 33, Goldwind imported the reliability growth DMATIC process and methods, which provides reliability growth with routine methods. They also imported the FSI concept and method for fault excitation and improvement, which greatly shortened the length of the reliability test making a breakthrough in the electronic product reliability test method.

After developing the "wind farm lifecycle management system" in 2014, Goldwind put it into use in more than 270 wind farms all over the world and the system has recorded more than 49,000 job tickets. In addition, Goldwind also promoted the progress of the

Goldwind Global Data Center. The Global Data Center has stored master data, O&M data, fault data, ten minutes data, and power curve data of more than 12,000 wind turbine generators. Goldwind also promoted the application of IEC61400-26-1-26-2 standard within the company.

### 4.2 Collaborative research

By the end of 2015, CWEA had organized 27 domestic wind power companies, research institutes, and universities to attend ten IEA Wind task meetings: Task 11 Base Technology Information Exchange, Task 19 Wind Energy in Cold Climates, Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power, Task 27 Small Wind Turbines at Turbulent Sites, Task 29 Aerodynamic Models, Task 30 Codes for Offshore Support Structures, Task 31 Windfarm Flow Models, Task 32 Lidar Systems for Wind Energy Deployment, Task 33 Reliability Data, and Task 35 Full Size Ground Testing of Wind Turbines and their Components.

Results relevant to the actual problems of wind power development in China are as follows:

1. Study of wind energy in cold climate—ice detection technology (Figure 2)
2. Numerical model validation of wind turbulence characteristics of building roofs
3. Thickness analysis of strong turbulent flow on roof (Figure 3)
4. Study of wind turbine reliability
5. Operation data collection—global monitoring system
6. Maintenance data collection—life cycle management system
7. Full scale ground testing wind turbine and its components (Figure 4)

Also, CWEA is considering taking part in IEA Wind Task 36 Forecasting for Wind Energy in 2016. We believe this cooperative research will play an important role in developing the wind energy industry, advancing wind energy technology, and maintaining wind energy as a sustainable energy option worldwide.

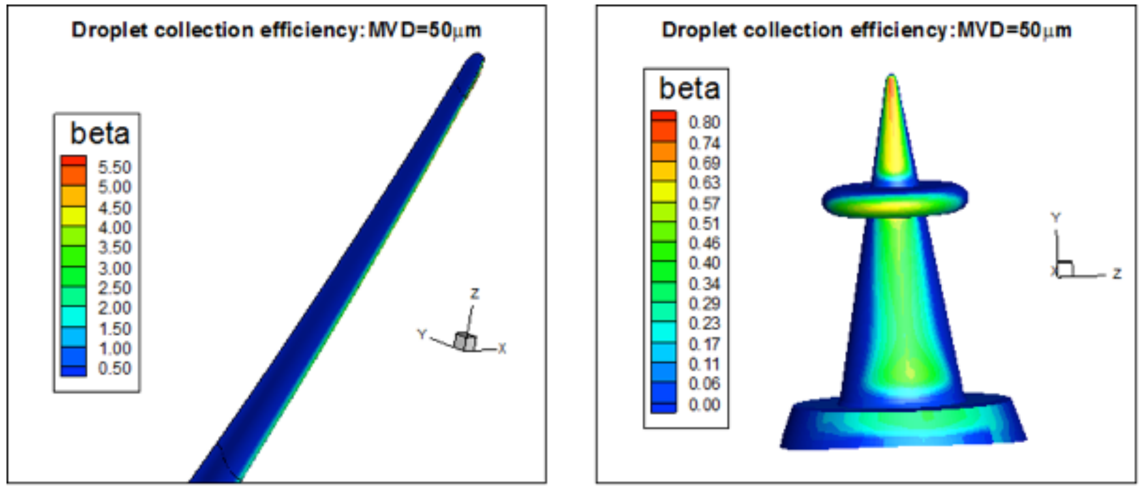

Figure 2. Ice detection technology

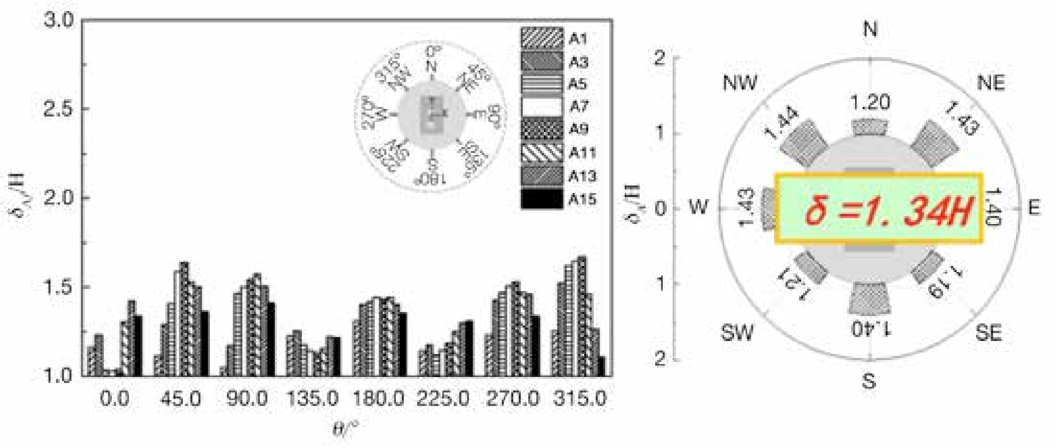

Figure 3. Thickness analysis of strong turbulent flow on roof

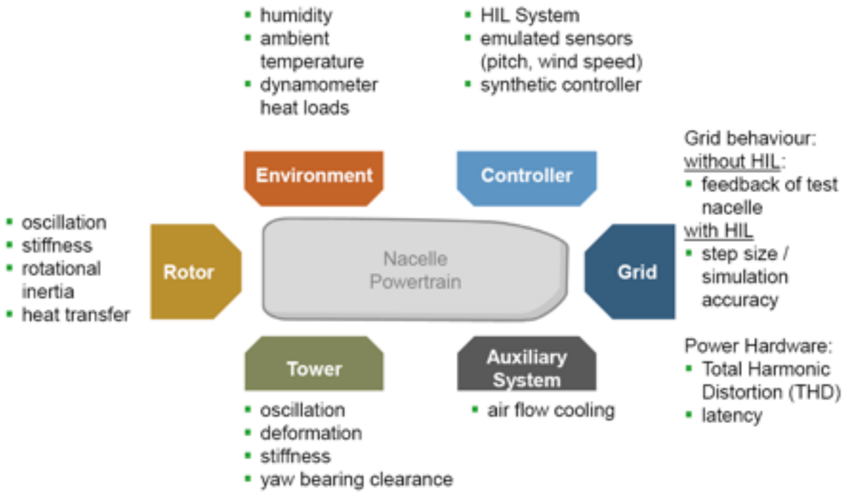

Figure 4. Full scale ground testing of wind turbine and its components

## 5.0 The Next Term

In 2015, the rate of wind power development in China remained at high levels and a record amount of new capacity was installed. This achievement was made possible by the release of the Energy Development Strategy Action Plan (2014–2020) and a series of policy measures to promote the development of wind power, to regulate the wind power market, and to further resolve wind power curtailment issues. It is estimated that wind power will continue the development in 2016, but not as much as 2015. With the rapid increase of wind power installations, the whole industry will focus on changing the development model, improving product quality, and advancing innovation.

The phase-in execution of the onshore FIT will propel the development of land-based wind power in China. All of these measures will become important drivers to take part in IEA Wind Tasks, and CWEA will continue to do its best to organize all related works.

**References:**

Opening photo: Wind farm in China (Photo credit: Xuejing Yu, Goldwind)

Authors: He Dexin, Du Guangping, and Wei Jia, Chinese Wind Energy Association (CWEA), China.

# 22 Denmark

## 1.0 Overview

**In 2015, 27.5% of Denmark's energy consumption came from renewable sources: 39.7% from oil, 17.0% from natural gas, 10.4% from coal, 2.5% from nonrenewable waste, and 3.0% from imported electricity. The production from wind turbines alone corresponded to 42% of the domestic electricity supply, compared to 39.1% in 2014. In 2015, total wind power capacity in Denmark was 5,077 MW (Table 1). New turbines totaling 223 MW were installed, while 40 MW were dismantled. No new wind turbines were installed offshore in 2015. The largest rated turbine is still the 8-MW Vestas erected at Oesterild test site at 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 report "Accelerating green energy towards 2020" [1], the publication "Energy Policy in Denmark," Danish Energy Agency (DEA), December 2012 [2]. The latest update is the Minister's report to Parliament 29 April 2015 (in Danish) [3].

There have been no new initiatives since July 2014, when the Danish government and the Parliament revised the agreement about financing the future development of wind power. The revision included the present plan for construction of Kriegers Flak before 2022 and the plans for near-coast offshore wind farms with a capacity of 400 MW. The future wind share is expected to be above 50% by 2020 and will increase further, when Krieger Flak is in full operation in 2022.

### 2.1 National targets

The Wind Power Agreement includes:

- 1,000 MW of large-scale offshore wind farms before 2022
  - -Horns Rev III 400 MW in operation in 2017–2020
  - -Krieger Flak 600 MW in operation before 2022 (EU support to grid connection 1.1 billion DDK (1.5 million EUR; 1.6 million USD)),
- 400 MW near-coast offshore installations (tendering process) including 50 MW of offshore turbines for R&D
- 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 to the domestic electricity supply was 42% in 2015 compared to 39.1% in 2014.

The added net wind capacity in Denmark in 2015 was 191 MW, bringing the total to 5,077 MW (Table 1). In 2015, 233 MW (621 new turbines) were installed, all on land, while 42 MW (112 turbines) were dismantled (Figure 2). A large portion (545 according to the Danish Agency register of wind turbines) of the new turbines were below 25 kW. Figure 3 shows the capacity and production of wind turbines in Denmark since 1980. A detailed history of Denmark's installed capacity and production in can be downloaded from the DEA website [4]. The largest rated turbine installed in 2015 was a MHI Vestas 8-MW in Maade, Esbjerg to test installation and operation procedures ahead of the machine's first deployment at Dong Energy's 258-MW Burbo Bank Extension offshore project in 2016. Also, a new Siemens 7-MW turbine was installed at the Oesterild Test Site in 2015.

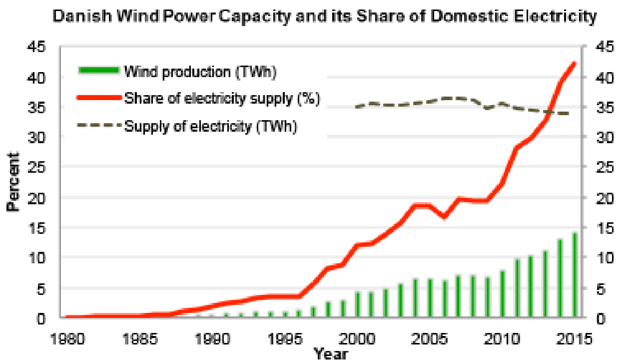

Figure 1. Wind power capacity and its share of electric demand in Denmark

At the end of 2015, a total of 2,847 turbines with a capacity of 513 MW had been dismantled since 1987. The average age of dismantled turbines is 17 years. Figure 4 shows the age distribution of dismantled turbines.

The environmental benefits due to the 2015 wind energy production have been calculated using preliminary data. Assuming coal is being substituted, saved coal = 4,689,009 tons (332 g/kWh); reduced $CO_2$ = 10,903,358 tons (772 g/kWh); reduced $SO_2$ = 989 tons (0.07 g/kWh); reduced $NO_X$ = 2,542 tons (0.18 g/kWh); reduced particles = 282 tons (0.02 g/kWh); and reduced cinder/ash 738,660 tons (52.3 g/kWh) [5].

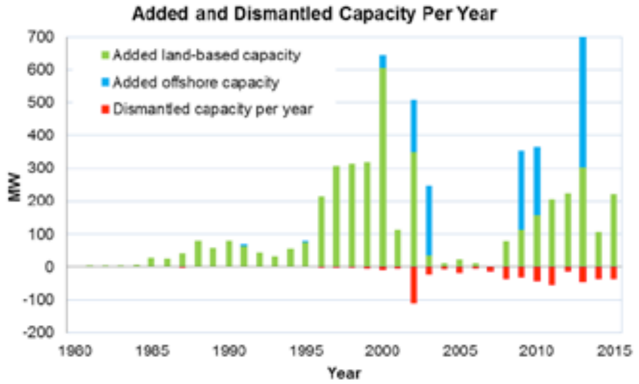

Figure 2. Added and dismantled capacity per year

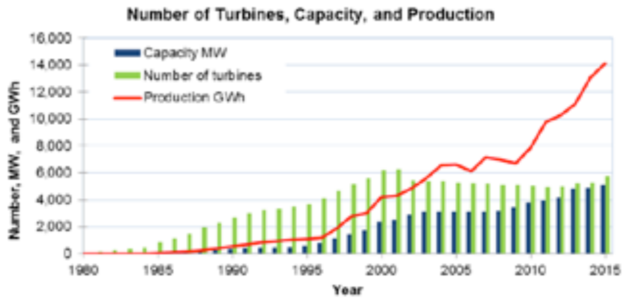

Figure 3. Number of turbines, capacity, and production from 1980 to 2015

### 2.3 National incentive programs

IIn 2014, the new feed-in premium tariffs for small wind turbines connected to the grid after November 2012 was introduced and came into force in 2015. Information about the existing incentive programs can be found in the *IEA Wind 2014 Annual Report*.

### 2.4 Issues affecting growth

The growth of wind energy in Denmark is affected by both policy and planning issues. The municipalities are in charge of the planning process of land-based wind turbines and the Danish Energy Agency is in charge of the offshore wind turbines. Vindinfo.dk samples the state information regarding the planning process, regulation, and legislation related to wind turbines [6]. It is a collaborative between the state departments involved in the planning process of wind turbines in Denmark. Vindinfo.dk is targeted toward municipalities, citizens, and the wind turbine development companies. At the English version of the site a new report "Energy Policy Toolkit on Physical Planning of Wind Power - Experiences from Denmark from 2015" provides technical and concrete information on Danish experiences and lessons learned on tools and measures in promoting renewable energy and energy efficiency [7].

In 2015, a new order on planning and permission for erection of wind turbines on land came into force together with a

**Table 1. Key National Statistics 2015: Denmark**

| | |
|---|---|
| Total (net) installed wind capacity | 5,077 MW |
| New wind capacity installed | 191 MW |
| Total electrical output from wind | 14.1 TWh |
| Wind-generated electricity as a % of national electric demand | 42.0% |
| Average capacity factor* | 32.6% |
| Wind target** | 50% of electricity demand by 2020 |

*Average capacity factor based on production from turbines installed before 1 January 2015
**Out of electricity demand

# 22 Denmark

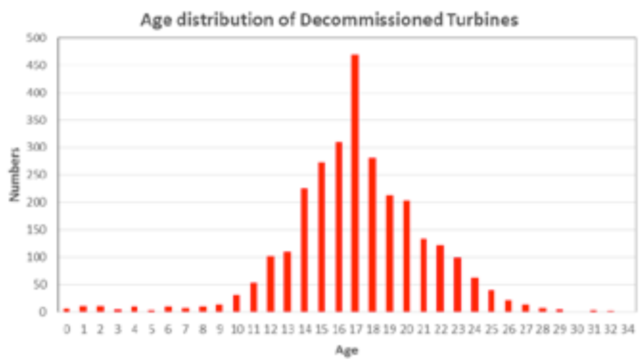

Figure 4. Age distribution of decommissioned turbines

comprehensive guideline on the regulations and practices developed during the previous years [8]. The guideline is supposed to help both municipalities and developers to make the process of erection of turbines as smooth as possible. The guideline references the latest knowledge, for example, on involvement of the local communities and avoiding noise and shadow effects as much as possible.

The Danish Energy Agency is in charge of the offshore planning and permissions and the regulation and procedures are described in previous Annual Reports. The latest information can be found on the Danish Energy Agency's (DEA) English website [9].

No new major policy initiatives have been taken in 2015, but the detailed planning process for the Horns Rev III (400 MW) and Kriegers Flak (600 MW) continued in 2015. The tendering materials for Horns Rev III were published at the end of 2014 and in February 2015 the winning tender came from Vattenfall Vindkraft A/S. They have agreed a price of 0.1031 EUR/kWh (0.1122 USD/kWh) over the next 11 to 12 years, which is the period during which the offshore wind farm will be in receipt of subsidies. Thereafter, the Horns Rev 3 facility will produce electricity at the market price and will no longer receive any form of subsidy.

After some delays, the tender for Kriegers Flak was published in late 2015. In October, DEA prequalified a total of seven companies and consortia to participate in the tender for Kriegers Flak, totaling 600 MW. The DEA will implement the tender during 2016. The prequalified companies selected are:

1. Kriegers Flak ApS (owned by Energie Baden Württemberg AG (EnBW AG)
2. Wpd HOFOR Stadtwerke München, Kriegers Flak SPV
3. European Energy Offshore Consortium (owned by European Energy A/S and Boralex Europe S.A.)
4. A not yet established company by Vattenfall Vindkraft A/S
5. Kriegers Flak Offshore Wind I/S (a not yet established company by Statoil ASA and E.ON Wind Denmark AB)
6. ScottishPower Renewable Energy Limited
7. DONG Energy Wind Power A/S

Information on tenders and progress for the planned 350-MW near-shore wind farms and the 50-MW test scheme for new offshore wind technology can also be found on the DEA English website [4]. The tendering process for the 350 MW is still ongoing. The DEA received five applications for prequalification, three of which have been invited to participate in the tender negotiations. The three prequalified applications are Wpd HOFOR Danish Offshore Consortium, European Energy Nearshore Consortium, and Vattenfall Vindkraft A/S. The tender will be finalized 1 September 2016.

The final winner of the 50-MW test scheme was published February 2016. The wining project was Nissum Broads Vindmøllelaug I/S with a 28-MW project "Testbed for new technologies and integrated design." The project includes testing four new 7.0-MW Siemens wind turbines (SWT-7.0-154) and a new bucket foundation concept (jacket type). The project site is Nissum Bredning in North West Jutland with conditions similar to the North Sea. The project is supported through a guaranteed feed-in tariff for the electricity produced at 0.70 DKK/kWh (0.094 EUR/kWh; 0.102 USD/kWh) in ten to11 years. The total funding for the project is estimated to be approximately 300 million DKK (40 million EUR; 44 million USD.)

## 3.0 Implementation

### 3.1 Industry

In 2015, the Danish wind industry increased its activities compared to 2014. However, exports fell in 2015 following a record high export in 2014. In 2015 the Danish wind industry turnover increased to 87.9 billion DKK (11.9 billion EUR; 12.9 billon USD) over the 85.4 billion DKK (11.5 billion EUR; 12.5 billion USD) in 2014 [10].

The wind industry's exports totaled 6.5 billion EUR (7.1 billion USD) in 2015, a decrease from 7.3 billion EUR (7.9 billion USD) in 2014. Compared to 2006, exports have gone up 22.6 percent and exports in 2014 hit the highest level since 2008-2009.

Employment levels in 2015 followed the increase in the turnover. By the end of 2015, 31,251 people were employed in the Danish wind industry factoring in people employed with energy companies. This is an increase of 3.8 percent since 2014.

Siemens was the largest wind turbine manufacturer in the offshore market in Europe in 2015 and Denmark ranks third in Europe when it comes to installed offshore wind capacity (after the UK and Germany). In 2015, Siemens added 1,816.4 MW of new capacity to their offshore network, which is now responsible for 60% of the European market in terms of annual installations. According to the annual statistics for offshore wind from EWEA, Siemens therefore remains the leading wind turbine manufacturer in the offshore market. Danish Vestas (MHI Vestas Offshore Wind) has been responsible for 12.9% of the market in 2015. More information is on the Wind Turbine Industry website [11].

### 3.2 Operational details

In Denmark, the largest projects are still 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 wind farm are shown in previous IEA Wind annual reports or on DEA website [9].

According to the Data Register of Wind Turbines for Denmark, 621 new turbines with a total capacity of 233 MW were added in 2015. Out

of those, 545 turbines had a capacity $\leq$ 25 kW, and 73 had a capacity between 2.0 MW and 8 MW. The register for wind turbines $\leq$ 25 kW was updated in May and June 2015, resulting in a large increase in the number of these turbines in the database, therefore showing many new small turbines in 2015.

At the end of 2015, 5,787 turbines with a capacity of 5,077 MW were in operation and the total production in the year was 14.1 TWh. The average capacity factor was 32.6% for the turbines, which have been in operation the whole year (average wind index 114%). The 1,271 MW of offshore wind farms alone counted for nearly 35% of the production (4.8 TWh) with an average capacity factor of 43.4%. This was a little less than 2014, partly because the submarine cable to the offshore wind farm Horns Rev 2 was out of service from mid-October to beginning of December.

The average capacity of turbines installed fell to 376 kW in 2015 because of the installation of many small household turbines. The average capacity of the 73 turbines above 1.0 MW was 3.1 MW. The largest rated turbine installed in 2015 was the first of two 8-MW MHI Vestas erected at Maade, Esbjerg in December 2015.

## 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 with Energinet.dk, the Energy Technology Development and Demonstration Program

**Table 2. Publicly Supported Wind Power Projects in 2015**

| Project | Company | Program | Grants (million DKK) | Grants (million EUR) | Grants (million USD) |
|---|---|---|---|---|---|
| DreamWind - Designing Recyclable Advanced Materials for WIND energy | Technological Institute | Innovations Foundation | 17.62 | 2.36 | 2.57 |
| RATZ and Reduction O&M cost of WT blades | BLADENA ApS | EUDP | 15.43 | 2.07 | 2.25 |
| TrueWind - Optimization of cup anemometer and wind tunnel calibration | DTU Wind Energy Dept. | EUDP | 9.19 | 1.23 | 1.34 |
| IEA Wind Task 36 Forecasting Danish Consortium | DTU Wind Energy Dept. | EUDP | 1.83 | 0.25 | 0.27 |
| Power System services for Renewable Energy Systems | DTU Wind Energy Dept. | ForskEL | 5.31 | 0.71 | 0.78 |
| IEA Wind Task 26: Cost of Wind Energy - phase 3 | EA ENERGIANALYSE A/S | EUDP | 1.2 | 0.16 | 0.18 |
| Leading Edge Roughness wind turbine blades | Power Curve ApS | EUDP | 12.54 | 1.68 | 1.83 |
| Full scale demonstration of an active flap system for wind turbines | DTU Wind Energy Dept. | EUDP | 11.15 | 1.49 | 1.63 |
| Offshore wind suction bucket on an industrial scale | SIEMENS WIND POWER A/S | EUDP | 9.96 | 1.33 | 1.45 |
| Medi Sander Wind | IN-Service ApS | EUDP | 1.74 | 0.23 | 0.25 |
| WakeBench2 – Benchmarking of Wind Farm Flow Models | DTU Environment | EUDP | 0.9 | 0.12 | 0.13 |
| Rain erosion tester for accelerated test of wind turbine blades | R&D Consulting Engineers | EUDP | 8.01 | 1.07 | 1.17 |
| Stretching wind turbine rotors using optimization | DTU Wind Energy Dept. | EUDP | 4.21 | 0.56 | 0.61 |
| IEA Wind Task 37, Systems Engineering/ Integrated R, D&D | DTU Wind Energy Dept. | EUDP | 0.98 | 0.13 | 0.14 |
| IEA Wind Task 25 - phase 4 | DTU Wind Energy Dept. | EUDP | 0.48 | 0.06 | 0.07 |
| Frederikshavn Offshore Demonstrater | UNIVERSAL FOUNDATION A/S | EUDP | 0.09 | 0.01 | 0.01 |
| Project activities under the IEA Wind TCP | J Lemming Rådgivning | EUDP | 0.12 | 0.02 | 0.02 |
| RUNE | DTU Wind Energy Dept. | ForskEL | 3.47 | 0.46 | 0.51 |
| HVAC Booster Turbine Concept | SIEMENS WIND POWER A/S | EUDP | 3.26 | 0.44 | 0.48 |

(EDDP), the Danish Council for Strategic Research (DCSR), the EC representation in Denmark, and the Danish Advanced Technology Foundation. The 2014 report is available online at together with an updated list of Danish funded energy technology research projects from 2014 (www.energiforskning.dk).

### 4.1 National R, D&D efforts

The main priorities for R, D&D in wind are still being defined in cooperation with the partnership Megavind [12]. The main strategy is still Megavind's report *The Danish Wind Power Hub* from May 2013 [13]. In May 2015 Megavind published the report *Danish Knowledge Institutions and their Contribution to a Competitive Wind Industry* [14]. This strategy focuses on increasing the ability of Danish knowledge institutions including universities and GTS institutes (research and technology organizations) to contribute in maintaining the Danish sector as world leader in the development of competitive wind power solutions. The strategy addresses in particular collaboration between business and knowledge institutions as well as industry involvement in research and development projects funded by public programs. The focus is on bringing companies with little or no experience in collaboration with knowledge institutions. The main target groups are researchers with wind energy related activities and R&D departments at small and medium sized companies and large component suppliers.

Furthermore, the strategy addresses the main barriers in making research created in knowledge institutions available for industry—including the commercialization of public funded research.

Detailed information on the activities and test sites at DTU and LORC can be found at their websites [16], [17].

A common website for Danish Research, Development, and Demonstration Funding Programs within Energy and Climate is Energiforskning.dk [15]. All funded projects can be found in the Project Gallery, as well as deadlines for applications and more information about the various programs. Funded projects are in a broad range from fundamental research to large-scale demonstration projects and ready-to-market projects. In 2015, the following 21 wind energy projects received grants with a total of 107.5 million DDK (14.3 million EUR; 15.7 million USD) (Table 2).

### 4.2 Collaborative research

Denmark has, in 2015, continued to take part in international co-operation regarding R, D&D in energy technologies. Public support is offered in order to promote that Danish companies and universities and 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 Technology Collaboration Progammes (TCPs) including IEA Wind. The Energy Technology and Demonstration Program (EUDP) is offering support to the costs of participating in the TCPs. More information can be found at www.iea.org/ and 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 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. The detailed planning of these two projects and the near-shore projects described in earlier annual reports continued during 2015. For more information see the DEA website [9]. The next step for Krieger's Flak is the implementation of the tendering process during 2016. The final decision and publication of the winning tender will be in December 2016. The next step for 350-MW near-shore project will be selection of the winner of the tender among the three pre-qualified companies. A political discussion on the support schemes for renewable energy (PSO) in the Spring 2016 might however result in postponing projects or even cancellation of the plans for near-shore 350 MW offshore projects.

A new strategy on test and demonstration facilities was released by Megavind in early 2016 [18]. It outlines recommendations within testing and demonstration of wind energy solutions in Denmark. The strategy points at eight key recommendations and has a full catalogue of ideas for test and demonstration facilities and competencies. Furthermore, it contains a mapping of global test and demonstration facilities. The report is expected to be the background for new negotiations with the Danish government in 2016.

Over the last three years, the EUDP program has been allocated more than 387 million DKK (52 million EUR; 56 million USD) on average annually. However for 2016, only 184 million DKK (25 million EUR; 27 million USD) will be allocated to EUDP.

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Opening photo: Anholt Wind Farm (Photo credit: DONG Energy)

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# 23 European Union/WindEurope

## 1.0 Overview

**In 2015, the EU connected 12.8 GW of new wind energy capacity, or 44% of total power capacity installations, for a cumulative wind capacity of 141.6 GW at the end of the year. The total net installed power capacity (including wind energy) increased by 11 GW, reaching 908 GW. Since 2000, 30% of new generating capacity installed has been wind power [1]. In 2015, wind energy generated 279 TWh of electricity meeting over 9.3% of EU power demand [2].**

**The EU programmes Horizon 2020, FP7, and Eureka funded wind Research and Innovation (R&I) projects that started in 2015 with 91.9 million EUR (100 million USD). In addition, two demonstration projects totaling 1,182.9 million EUR (199 million USD) of public funding under the NER 300 programme reached final investment decision in 2015. NER 300 is a financing instrument managed jointly by the European Commission, European Investment Bank, and Member States.**

## 2.0 EU Objectives and Progress

The main legislation in the EU promoting the deployment of wind energy is the Renewable Energy Directive that came into force in 2009. It sets a target of 20% renewable energy in gross final energy consumption at EU level, broken down into 28 distinct national targets. This target corresponds to 34% of renewables in EU power demand [3].

The European heads of state also set a binding renewable energy EU-wide objective of at least 27% in the context of the 2030 Energy Strategy. Currently, the European Commission and other stakeholders are working on several legislative proposals to be presented in the last quarter of 2016 and likely to affect wind energy development to 2030. The European Commission will define the details of the governance for the post-2020 energy and climate strategy and in particular the means to reach the EU 2030 renewable energy target and the design of the EU power market. In addition, proposals will be presented on security of energy supply and the electricity interconnection target for 2030. Such legislations will be crucial to establish a clear and stable legislative framework for wind energy to effectively continue providing clean electricity to the European Union.

### 2.1 EU targets

The EU target is 20% share of renewable energy in final energy consumption by 2020. Specifically for wind energy, targets are taken from the National Renewable Energy Action Plans (NREAPs), where EU Member States describe the detail of how they will achieve the 20% renewable energy share. The latest feedback, 2015 progress reports by the Member States, reduced the overall target somehow, to 476 TWh of electricity. That corresponds to 170 GW of land-based wind and 37 GW of offshore wind capacity, for a total of 207 GW. The current EU-wide target for 2030 is a 27% share of renewables in final energy consumption, with no estimate of wind energy share.

### 2.2 Progress

By the end of 2015, Croatia, Denmark, Germany, and Sweden had already achieved their 2020 self-proposed wind energy targets, whereas Austria, Lithuania, and Poland are already within 15% of reaching their targets. On the opposite end, other countries such as Bulgaria, the Czech Republic, Estonia, Hungary, Latvia, Luxemburg, Malta, Slovakia, and Slovenia are not only far from their targets (less than 50%), but do not have policies in place for reaching them [4].

Other countries have achieved a large part of their target, but some, such as Spain, Romania, and the United Kingdom, have put policies in place that will likely prevent them from reaching their 2020 self-defined targets. In particular, Spain implemented in 2014 a regulatory system establishing in principle the maximum profit wind farm operators should make and adjusted the support to that. The system runs retroactively and excludes wind farms commissioned before 2004, for which support was cancelled altogether. In 2015, the United Kingdom cancelled the support for new land-based wind energy as from April 2016 with a one-year grace period under certain circumstances [5].

### 2.3 EU incentive programs

Wind energy in the European Union was originally supported by feed-in tariff mechanisms, which boosted the growth of the industry by providing wind energy assets operators a stable and guaranteed cash flow over the lifetime of the asset. Support mechanisms then evolved to more market-oriented schemes such as feed-in premiums, providing to asset operators a premium on top of the electricity price.

Following the 2014 European Commission Energy and Climate State Aid Guidelines, Member States are progressively introducing feed-in premium support mechanisms, often coupled with competitive allocation processes such as auctions. Countries which have already changed their regulatory schemes in this sense or are in the process of changing them include Italy, the Czech Republic, Denmark, Germany, Poland, Spain, and the UK.

### 2.4 Issues affecting growth

Unstable regulatory and political frameworks are hampering wind energy development in some Member States. Sudden changes in the legislation together with retroactive changes are the biggest threats to wind energy investors. Recent examples of counterproductive regulatory changes took place in Spain, Romania, and the UK.

Local planning and environmental impact regulations also represent bottlenecks to wind energy project development. Permitting procedures should be harmonized with local environmental and planning requirements as well as with grid requirements. This is a great concern for the European wind energy industry, which is helping addressing these challenges working with local authorities and communities to increase local participation in the planning and implementation of wind power projects [6].

In several countries, wind energy generation is curtailed if power demand in the system is already met by other sources. Unclear rules and, in certain cases, lack of compensation for curtailment, increase risk for wind power operators.

## 3.0 Implementation

In 2015, 47% of all new EU installations took place in Germany and 73% occurred in the top four markets, a similar trend to the one seen in 2014. Poland came second with 1,266.4 MW, more than twice the annual installations in 2014 and one quarter of its national cumulative capacity at the end of 2015. France was third with 1,073.1 MW, and the UK fourth with 975.1 MW, 59% of which was offshore (572.1 MW) [1].

Also during 2015, 3,018.5 MW of new offshore wind power capacity was connected to the grid in Europe, a 108.3% increase over 2014 and the biggest yearly addition to capacity to date. Of all net capacity brought online, 75.4% was in Germany (2,282.4 MW), a four-fold increase in its grid-connected capacity compared to 2014. This was in large part due to the delay in grid connections which allowed wind farms installed in 2014 to only come online in 2015. The second largest market was the UK (566.1 MW, or 18.7% share), followed by the Netherlands (180 MW, or 5.9% share). Offshore wind accounted for 24% of total EU wind power installations in 2015, confirming the growing relevance of the offshore wind industry in the development of wind energy in the EU [1].

### 3.1 Economic impact

Annual Investment in the wind energy sector reached a record in 2015. Financial commitments in new assets totaling 9.7 GW of new gross capacity reached a total of 26.4 billion EUR (28.7 billion USD), a 40% increase from 2014. While investments in new land-based wind generating assets increased by 6.3% in 2015, those in the offshore wind sector doubled compared to the previous year. In particular, ten offshore wind projects worth more than 13 billion EUR (14 billion USD) in total reached final investment decision in 2015 and thus more than 3 GW of new gross capacity were financed.

The UK had the highest level of investments in 2015, attracting 12.6 billion EUR (13.7 billion USD) for the construction of new land-based and offshore wind farms or 48% of the total investments made in 2015. About two thirds of the new financial commitments in 2015 for renewable energies went to the wind power sector [1].

Non-wind energy-related players continue to invest in the wind energy sector. Global corporations such as Google and IKEA invest in wind energy assets to power their facilities or sign power purchase agreements with wind energy operators to compensate for the emissions of their electricity use. Those and other corporations such as LEGO and Unilever are turning to wind energy to save on energy costs because of wind energy's competitiveness vis-á-vis other electricity sources. Investment funds, institutional players such as pension funds

**Table 1. Key National Statistics 2015: European Union**

| | |
|---|---|
| Total (net) installed wind energy capacity | 141,600 MW |
| New wind energy capacity installed | 12,800 MW |
| Total electrical output from wind energy | 279 TWh |
| Wind-generated electricity as a % of national electric demand | 9.3% |
| Average EU capacity factor | 23.4% |
| Target: | 486 TWh by 2020 |

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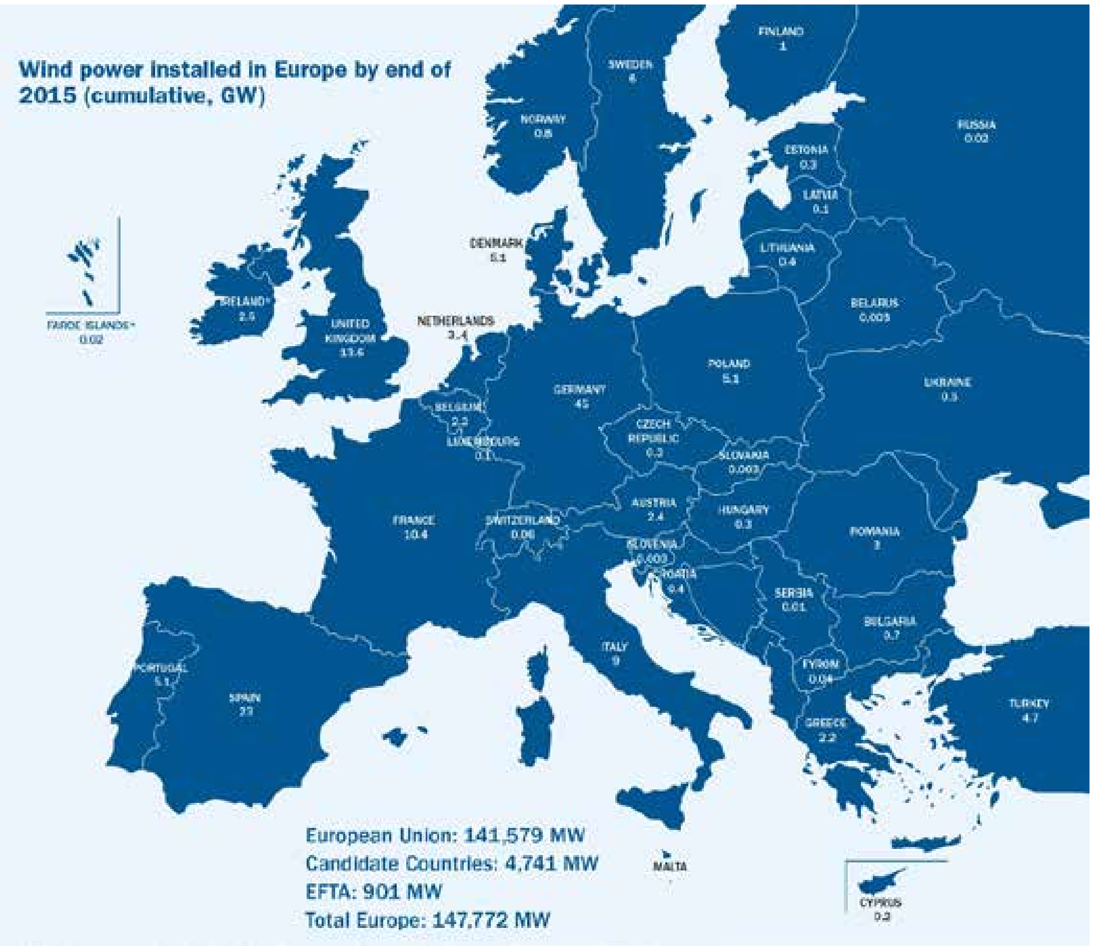

Figure 1. Wind power installations in Europe by end of 2015 (Source: WindEurope [1])

and insurance companies like Allianz, and banks such as BNP Paribas are as well investing resources in wind energy because of its stable return on investments.

The wind energy industry shares benefits with local communities and authorities. For example, the wind energy industry in Scotland contributes 8.8 million GBP/yr (11.9 million EUR/yr; 13.0 million USD/yr) to local communities. In the United Kingdom, the standard community benefit fund for new projects is 5,000 GBP/MW (6,775 EUR/MW; 7,375 USD/MW) installed on an annual basis [8].

### 3.2 Industry status

The European wind turbine manufacturing sector is under pressure from non-European manufacturers. Non-European wind turbines original equipment manufacturers (OEMs) are gaining increased shares of the global market. A consolidation phase started in 2014 in the EU and is currently ongoing, with Spanish Gamesa merging its offshore business with French Areva, American General Electric acquiring the energy business of French company Alstom, and German wind turbine manufacturer Nordex acquiring the wind turbine manufacturing business of Spanish Acciona Energía Internacional. The latter deal is likely to create a global wind energy player, as Nordex is a medium-size manufacturer with a strong position in Germany, while Acciona Windpower has been focussing on American markets for the last years. Lately, Spanish manufacturer Gamesa and German engineering company Siemens started discussions about a potential takeover of the former by the latter [9].

First financial reports by European OEMs show that they have generally improved their results. They have been able to react to the European financial crisis and return to healthy financial conditions, supported also by their global operations. For the five companies who had disclosed this information at the time of writing (Gamesa. Senvion, Acciona. Nordex and Vestas), EBIT increased from 1,650 million EUR (1,795 million USD) in 2014 to 2,200 million EUR (2,394 million USD) in 2015, a 33.5% increase. For these companies turbine sales increased by 27% in MW terms, which compares with a 12.6% increase in global market excluding China [10].

### 3.3 Operational details

As technology progresses, the industry is exploiting wind energy sites with lower wind energy resources. Bigger wind turbines with higher capacity factors and higher numbers of full load hours of operation over their lifetime are being manufactured to make use of lower speed winds.

Land-based wind turbines in the range of 2.99–3.30 MW were the most ordered in the EU in 2015 (for a total capacity of 1.4 GW), while in the offshore segment, the market moved to bigger wind turbines between 7.0 and 8.2 MW (2.1 GW of capacity ordered) [10]. Both utility scale projects as well as community-based wind farms are being developed, showing the versatility of the technology. Almost half of the capacity ordered in 2015 was for wind energy projects of more than 30 MW and around 10% of the total capacity ordered in 2015 was for small projects of up to 10 MW [11].

Data shows capacity factors in the EU Member States range between 17.6% in Cyprus and 33% in Sweden with the EU average being 23.5% in 2015 [2]. Calculations on 2014 based on Eurostat data estimate wind energy average capacity factor in the EU at 23.4% [12]. With the evolution of technology, new wind farms have higher capacity factors. WindEurope estimates that land-based wind energy capacity factor in some areas of the EU as well as new wind farms all around the EU is around 24% and offshore wind energy capacity factor is 42% [1]. Wind energy capacity factor and offshore wind energy capacity factor in particular is likely to grow significantly over the next years due to the ongoing trend towards bigger, taller and more efficient wind turbines.

### 3.4 Wind energy costs

Global figures presented in OEM annual reports suggest that wind turbine unit prices continued to decrease, as shown in Figure 2. Although the actual figures have to be taken with caution as they do not correspond to a fully-consistent series of data points with equal characteristics. For example, the percentage of the more expensive offshore turbines changes with the year. Even with these data limitations, the graph shows that the trend to lower prices that was clear until 2014 was slightly reversed in 2015. This is consistent with the increase in profits of most OEMs in 2015 compared to 2014, and with the impressive increase in global wind turbine demand. These figures are based on global sales.

## 4.0 R, D&D Activities

Two thousand fifteen saw the launch of the first projects under the new R&I programme Horizon 2020 (H2020). With a total budget of 5.93 billion EUR (6.45 billion USD) for its energy part until 2020, H2020 provided 90 million EUR (98 million USD) in 2015 for 28 wind energy-related projects, based on the date each project officially started, as shown in Table 2. This table and the subsequent analysis exclude projects with a total cost below EUR 100,000 (108,800 USD).

Projects focus on wind energy technology but could also affect other technologies (e.g., smart grids), therefore the difference between columns EC funding and EC wind-specific funding [12].

H2020 is increasingly active: ten wind-related research projects worth 177 million EUR (193 million USD), of which 124 million EUR (135 million USD) was funded by the EC, were launched in 2016 until 1 March.

### 4.1 European Union R, D&D efforts

EU R, D&D or R&I priorities embrace the whole spectrum of elements necessary to reduce the cost of wind energy: basic and applied research, and demonstration. These priorities were grouped as follows [13]:

- New turbines, materials and components
- Resource assessment
- Offshore technology
- Logistics, assembly, testing, installation and decommissioning
- Grid integration
- Spatial planning, social acceptance and end-of-life policies

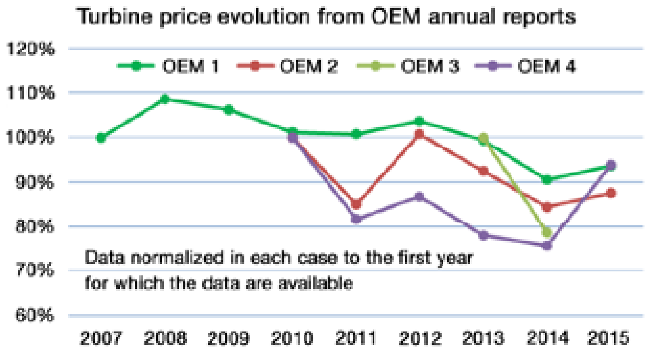

Figure 2. Turbine price evolution 2007–2015

**Table 2. EC and Wind Energy-Specific Funding under H2020 of R&I Projects Started in 2015**

| H2020-funded R&I projects | Million EUR | Million USD |
|---|---|---|
| Total project cost | 123.73 | 134.62 |
| EC funding of wind projects | 90.30 | 98.24 |
| Share of wind-specific research of projects | 66.65 | 72.52 |

Figure 3 shows how the R&I priorities translated into actual projects since 2008, with projects granted not only under H2020 but also under its predecessors FP7 and IEE, and under Eureka. Table 3 shows the detailed data.

Item "other" in Figure 3 includes exploratory R&D such as kites or other R&I grants focused on helping to improve the technology but do not represent research as such: for example, support for the technology platform or for PhD programs.

The total EC funding specifically dedicated to wind energy technology has increased from 42 million EUR (46 million USD) in the biennium 2008/2009 to 127 million EUR (138 million USD) in 2012/2013 before

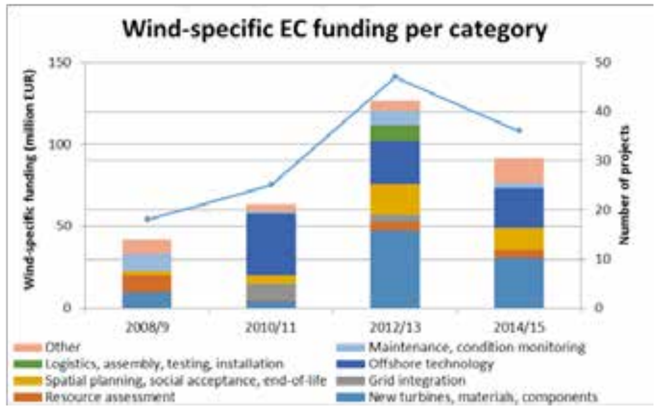

Figure 3. Evolution of EC R&I funding specifically for wind-related activities and number of projects per biennium (the blue line corresponds to the number of projects against the right axis) [12]

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**Table 3. Detailed EC Funding for Wind-Specific R&I Projects Starting 2008–2015 (million EUR; million USD)**

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| New turbine materials, components | 6.0; 6.5 | 3.9; 4.2 | 2.9; 3.2 | 1.1; 1.2 | 25.4; 27.6 | 21.9; 23.8 | 8.5; 9.3 | 22.1; 24.1 | **91.8; 99.9** |
| Resource assessment | 10.4; 11.3 | 0.3; 0.33 | 0.5; 0.54 | | 4.4; 4.8 | 1.1; 1.2 | 4.3; 4.7 | 0.8; 0.87 | **22; 24** |
| Grid integration | | | 10.1; 11.0 | | 2.0; 2.2 | 1.9; 2.1 | | 0.1; 0.11 | **14.1; 15.3** |
| Spatial planning, social acceptance, end-of-life | 1.1; 1.2 | 1.0; 1.1 | 2.7; 2.9 | 3.0; 3.3 | 18.9; 20.6 | 0.1; 0.11 | 11.8; 12.8 | 1.1; 1.2 | **39.9; 43.4** |
| Offshore technology | | | 17; 18.5 | 20.4; 22.2 | 6.2; 6.7 | 20; 21.76 | | 24.3; 26.4 | **87.8; 95.5** |
| Logistics, assembly, testing, installation | | | | | | 10; 10.9 | | | **10; 10.9** |
| Maintenance, condition monitoring systems | 7.2; 7.8 | 3.4; 3.7 | | 1.3; 1.4 | 4.0; 4.4 | 4.4; 4.8 | | 2.9; 3.2 | **23.2; 25.2** |
| Other | 0.7; 0.76 | 8.1; 8.8 | 1.9; 2.1 | 2.6; 2.8 | 0.4; 0.44 | 6.2; 6.8 | | 15.7; 17.1 | **35.5; 38.6** |
| **Total** | **25.3; 27.5** | **16.7; 18.2** | **35.2; 38.3** | **28.4; 30.1** | **61.3; 66.7** | **65.6; 71.1** | **24.7; 26.9** | **67.0; 72.9** | **324.2; 352.7** |

being reduced to 92 million EUR (100 million USD) in 2014/2015. The reason for the later reduction is the change of program in 2014 from FP7 to H2020 and the necessary administrative adjustments.

The average EC funding for the wind energy-specific part of the research was stable around 2.2–2.8 million EUR/project (2.4–3.0 million USD). The highest-funded project was 19.6 million EUR (21.3 million USD) and several small projects were funded with less than 100,000 EUR (108,800 USD) are not included in the figures here. Amongst all EU-funded wind energy projects, the grid-wind energy project TWENTIES is the largest project funded with a total cost of 56.8 million EUR (61.8 million USD) of which the EC contributed 25 million EUR (27 million USD). Of this amount, 30% is considered to be wind energy-specific and is included in Table 3.

In 2015, 28 projects with a budget greater than 100,000 EUR (108,800 USD) started under the H2020 programme. Included in these projects are the large DemoWind projects (which could actually be considered a subprogramme because they launche their own research calls). Of the 28, three projects (ELISA, LIFES50+, and TELWIND) focus on floating substructures. The EC and Member States funded DemoWind (split 30%/70%) which will also focus on offshore technologies. Aerodynamics, superconductor generators, airborne wind, materials, O&M, education and training, and small turbines complete the areas with the largest funding.

New key projects starting in 2015 include one project on training, two projects on airborne turbines (AWESCO and AMPYXAP3), a superconductor generator, and plenty of support for research.

- AEOLUS4FUTURE will support training and education at the engineering and research level with primary research aims including: assessment of wind energy potential (offshore and land-based, including the built environment); design of a sustainable and highly efficient wind turbine; and analysis of turbine load conditions in complex terrain.
- AWESCO will explore airborne turbines ("a fast flying high efficiency kite") with power generated either by periodically pulling a ground-based generator via a winch, or by small wind turbines mounted on the kite that exploit its fast cross wind motion. The project will support innovative junior researchers in a closely co-operating consortium of academic and industrial partners.
- AMPYXAP3 will develop "autonomous aircraft tethered to a generator on the ground", moving in a regular figure-8 pattern at an altitude of up to 450 m. When the aircraft moves, it pulls the tether which drives the generator. Once the tether is reeled out to a pre-defined tether length, the aircraft automatically descends towards the ground causing the tether to reel in. Then it ascends and repeats the process.
- EcoSwing is probably the most significant project started in 2015, based ambition and its 13.85 million EUR (15.1 million USD) budget. Lead by the Danish subsidiary of Chinese wind turbine manufacturer Envision, EcoSwing aims at world's first demonstration of a superconducting low-cost, lightweight direct-drive train on a modern 3.6-MW wind turbine.
- LIFES50+ attempts to develop floating substructures for 10-MW wind turbines at water depths from 50–200 m. Three other projects focus on floating structures, ELISA, FLOATMAST and TELWIND.
- Finally DemoWind, as mentioned in the IEA Wind 2014 report, co-funded with a total 21.2 million EUR (23.0 million USD) from EU Member States (Belgium, Denmark, the Netherlands, Portugal, Spain, and the UK) that is matched with 10.4 million EUR (11.3 million USD) of funding from the EC. DemoWind has launched its first calls for projects to demonstrate technologies which can lower the cost of offshore wind technology. Table 4 lists projects started in 2015 and their funding levels. When the main technology is not wind, these projects still have an impact on wind technologies.

## 5.0 The Next Term

Several projects came to a close in 2015. A decision was to stop a major project, HIPRWIND. This project aimed at "creating and testing at the megawatt scale novel, cost effective approaches to floating

**Table 4. Wind-Related R&I Projects Started in 2015 Partly or Wholly Funded by EU Institutions (million EUR; million USD)**

| Action (IR) | Area | Funding programme | Short name or Acronym | Total budget (million EUR; million USD) | Public budget (million EUR; million USD) | Wind share (million EUR; million USD) | From | Months | Main technology |
|---|---|---|---|---|---|---|---|---|---|
| New turbines. materials and components | Cold climate, blade | NER I | Vindpark Blaiken | 15.00; 16.32 | 15.00; 16.32 | 15.00; 16.32 | 31/08/15 | 8 | Wind |
| | Aerodynamics | H2020 | Riblet4Wind | 4.03; 4.38 | 3.31; 3.60 | 3.31; 3.60 | 01/06/15 | 42 | |
| | | | Rotary Wing CLFC | 0.17; 0.185 | 0.17; 0.185 | 0.17; 0.185 | 01/05/15 | 24 | |
| | | | AEROGUST | 4.29; 4.67 | 4.24; 4.61 | 0.85; 0.93 | 01/05/15 | 36 | Aviation |
| | Design tools | | HPC4E | 2.00; 2.18 | 2.00; 2.18 | 0.20; 0.22 | 01/12/15 | 24 | ICT |
| | Gearbox | | S-Gearbox | 0.07; 0.076 | 0.05; 0.054 | 0.01; 0.011 | 01/06/15 | 6 | Materials |
| | Materials | | AEROFLEX | 1.38; 1.50 | 1.38; 1.50 | 0.07; 0.076 | 01/07/15 | 60 | |
| | | | CRYOMAT | 1.50; 1.63 | 1.50; 1.63 | 0.07; 0.076 | 01/06/15 | 60 | |
| | | | FLOVISP | 0.15; 0.16 | 0.15; 0.16 | 0.02; 0.022 | 01/06/15 | 18 | |
| | | | REE4EU | 9.06; 9.89 | 7.52; 8.18 | 2.26; 2.46 | 01/10/15 | 48 | |
| | Nacelle other | | SPARCARB | 1.09; 1.19 | 1.093; 1.189 | 1.09; 1.19 | 01/01/15 | 48 | Wind |
| | Superconductor generators | | EcoSwing | 13.85; 15.07 | 10.59; 11.52 | 10.59; 11.52 | 01/03/15 | 48 | |
| | Thermoplastics | | ambliFibre | 4.74; 5.16 | 4.74; 5.16 | 1.89; 2.06 | 01/09/15 | 36 | Materials |
| | Tower | | LiraTower | 0.07; 0.076 | 0.05; 0.054 | 0.05; 0.054 | 01/08/15 | 4 | Wind |
| | | | SE-NBW | 0.07; 0.076 | 0.05; 0.054 | 0.05; 0.054 | 01/10/15 | 6 | |
| | Wind farm control | | VirtuWind | 6.34; 6.90 | 4.87; 5.30 | 2.44; 2.65 | 01/07/15 | 36 | ICT |
| Grid integration | Electricity markets | FP7 | SOPRIS | 0.27; 0.29 | 0.27; 0.29 | 0.08; 0.087 | 15/05/15 | 36 | Grids |
| Spatial planning. Social acceptance. end-of-life | Environmental | H2020 | RiCORE | 1.39; 1.51 | 1.39; 1.51 | 0.56; 0.61 | 01/01/15 | 18 | Ocean |
| | Grid integration | | IndustRE | 1.90; 2.07 | 1.90; 2.07 | 0.19; 0.21 | 01/01/15 | 36 | Markets |
| | Social acceptance | | CrowdFundRES | 1.99; 2.17 | 1.89; 2.06 | 0.38; 0.41 | 01/02/15 | 36 | |

table continued on next page

# 23 European Union/WindEurope

| Action (IR) | Area | Funding programme | Short name or Acronym | Total budget (million EUR; million USD) | Public budget (million EUR; million USD) | Wind share (million EUR; million USD) | From | Months | Main technology |
|---|---|---|---|---|---|---|---|---|---|
| Maintenance. CMS | Maintenance | Eureka | SafeWindTurbine |  | 0.81; 0.88 | 0.81; 0.88 | 01/10/15 | 36 | Wind |
|  |  | H2020 | AWESOME | 2.86; 3.11 | 2.86; 3.11 | 2.86; 3.11 | 01/01/15 | 48 |  |
| Offshore technology | Fixed foundations | NER300 | Nordsee One | 140.00; 152.32 | 70.00; 76.16 | 70.00; 76.16 | 31/12/15 | 84 |  |
|  |  |  | Veja Mate I |  | 112.60 | 112.60 | 30/06/15 | 66 |  |
|  | Floating foundations | H2020 | ELISA | 3.57; 3.88 | 2.50; 2.72 | 2.50; 2.72 | 01/06/15 | 24 |  |
|  |  |  | FLOATMAST | 0.07; 0.076 | 0.05; 0.054 | 0.05; 0.054 | 01/06/15 | 6 |  |
|  |  |  | LIFES 50plus | 7.27; 7.91 | 7.27; 7.91 | 7.27; 7.91 | 01/06/15 | 40 |  |
|  |  |  | TELWIND | 3.50; 3.81 | 3.50; 3.81 | 3.50; 3.81 | 01/12/15 | 30 |  |
|  | Multi-use platform |  | POSEIDON | 1.63; 1.77 | 1.14; 1.24 | 0.57; 0.62 | 01/06/15 | 24 | Ocean |
|  | Diverse offshore technologies |  | DemoWind | 31.64; 34.42 | 10.44; 11.36 | 10.44; 11.36 | 01/01/15 | 60 | Wind |
| Other | Airborne wind |  | AMPYXAP3 | 3.70; 4.03 | 2.50; 2.72 | 2.50; 2.72 | 01/04/15 | 23 |  |
|  |  |  | AWESCO | 3.00; 3.26 | 3.00; 3.26 | 3.00; 3.26 | 01/01/15 | 48 |  |
|  |  |  | REACH | 3.73; 4.06 | 2.68; 2.92 | 2.68; 2.92 | 01/12/15 | 38 |  |
|  | Education and training |  | AEOLUS4FUTURE | 3.81; 4.15 | 3.81; 4.15 | 3.81; 4.15 | 01/01/15 | 48 |  |
|  |  |  | ICONN | 0.85; 0.93 | 0.85; 0.93 | 0.42; 0.46 | 01/10/15 | 48 | Ocean |
|  |  | FP7 | OHMWIT | 0.27; 0.29 | 0.27; 0.29 | 0.27; 0.29 | 01/01/15 | 24 | Wind |
|  | Small turbines | H2020 | Eciwind | 1.87; 2.03 | 1.31; 1.43 | 1.31; 1.43 | 01/05/15 | 24 |  |
|  |  |  | IRWES (2) | 2.42; 2.63 | 1.70; 1.85 | 1.70; 1.85 | 01/04/15 | 23 |  |
|  |  |  | URBAVENTO | 0.07; 0.076 | 0.05; 0.054 | 0.05; 0.054 | 01/09/15 | 6 |  |

offshore wind turbines," including "a fully functional floating MW-scale wind turbine." Other projects finishing their work in 2015 include the Windscanner research on LIDAR, SEEWIND, MARINET and EERA-DTOC, among others. The latter is possibly the most successful FP7 project as it developed a "multidisciplinary integrated software tool for an optimised design of offshore wind farms and clusters of wind farms" that was launched as an independent company (see www.wind-and-economy.com).

Other EU-funded projects commissioned in 2015 include demonstration projects funded by the European Economic Programme for Recovery (EEPR) and the New-Entrant Reserve (NER 300). These are the offshore wind farms Borkum West II (now called Trianel Windpark Borkum) and Nordsee Ost, which were funded by EEPR with 42.7 million EUR (46.5 million USD) and 50 million EUR (54.4 million USD) respectively for the demonstration of tripod foundations (Borkum West II) and of large turbines on jacket foundations (Nordsee Ost). The 225-MW, 90-wind turbine wind farm Blaiken in Sweden was supported by NER 300 in its demonstration of ice-prevention and de-icing systems with two different turbine models by European Nordex and Chinese Dongfang manufacturers. Although these projects were commissioned in 2015, the monitoring of the performance of their innovative features will continue for some years. Recent years, in particular 2014 with 12 GW and 2015 with 13 GW, have registered record installations of wind power in the EU. Mature wind energy markets had the lion's share of new installations but also new developing markets such as Poland contributed considerably. Such development shows that wind energy is a mature industry which makes economic sense and is contributing significantly to Europe's energy security and competitiveness goals.

However, such growth is geographically uneven because in several countries the policy and regulation is unclear or ineffective, e.g., Malta, Slovakia, or Slovenia, or policy is reversing against wind energy, e.g., Poland. Long-term policy is important because in 2015 only six out of the 28 EU states had clear targets and policies in place for renewables post-2020.

Wind energy is expected to grow both in installations and in share of final electricity demand and generation in the years leading up to 2020 although growth after 2020 is less certain because sectoral targets are lacking in the overall renewable energy target. The industry is working hard to cut costs and improve its processes' efficiency along the whole value chain but it must rely on a clear and stable regulatory framework.

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Opening photo: Instrumentation and lighting on the nacelle of a multi-megawatt wind turbine (Source: GE Renewable Energy)

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# 24 Finland

## 1.0 Overview

**Finland is a 15-GW winter-peaking power system with 83 TWh of electrical demand in 2015. Thirty six percent of electricity consumption was provided by renewables in 2015: 20% by hydro power, 13% by biomass, and 3% by wind power. Installed wind power reached 1,005 MW at the end of 2015, generating 2.3 TWh. The target is 6 TWh/yr in 2020 and 9 TWh/yr for 2025.**

**Construction of wind power started growing in Finland in 2012 following the legislation for guaranteed price for renewable generation, which was set in 2010. In 2015, the new government announced their decision to cut the subsidy scheme, but before the new law was passed, the quota of 2,500 MVA (mega-volt amperes) was filled with applications. If all the projects in the quota are built within the allowed two year limit, 4.5–6 TWh/year is expected by 2018.**

**A new subsidy scheme fulfilling the new EU guidelines for technology neutrality and auctioning is currently being prepared and it will be further outlined in the national energy and climate strategy by the end of 2016. Wind power technology in Finland employs 2,000–3,000 people in the wind power industry and 2,200 in project development, construction, and O&M.**

## 2.0 National Objectives and Progress

### 2.1 National targets

As part of the EU 20% target, the target set for renewable energy sources (RES) in Finland is 38% of final energy consumption in 2020. This target has been achieved with the RES share in 2015 exceeding 39%. The target set for wind power in the 2008 climate and energy strategy was 6 TWh/yr for the year 2020, corresponding to 6–7% of the total electricity consumption in Finland. The energy strategy published in 2013 has an increased target for wind power of 9 TWh/yr in 2025. A new energy and climate policy as well as new subsidy system is currently in preparation.

### 2.2 Progress

The implementation of the guaranteed price system has led to a market of nearly 400 MW/yr. Production from wind power more than doubled in 2015, to 2,329 GWh. This corresponds to 3% of the annual gross electricity consumption of Finland (Table 1). The environmental benefit of wind power production in Finland is about 1.6 million tons of $CO_2$ savings per year, assuming 700 g/kWh $CO_2$ reduction for wind power (replacing mostly coal and some gas power production).

Total wind capacity in Finland was 1,005 MW by the end of 2015, of which 379 MW (123 turbines) new capacity were installed and 5 MW were dismantled in 2015 (Figure 1). The production index in the figure gives the yearly generation compared to long term average (100%), calculated for five example sites based on FMI wind measurements.

The new wind farms have 2 to 22 turbines each with total capacity ranging from 6 MW to 73 MW and turbines ranging from 2.4 MW to 3.3 MW (average: 3.1 MW). The largest wind power plants were erected in Mustilankangas (22, 3.3-MW turbines, three of which started generation in 2016 and are not included in the end of year capacity) and Torkkola (12, 3.3-MW turbines in 2015 and four, 3.3-MW turbines in 2014).

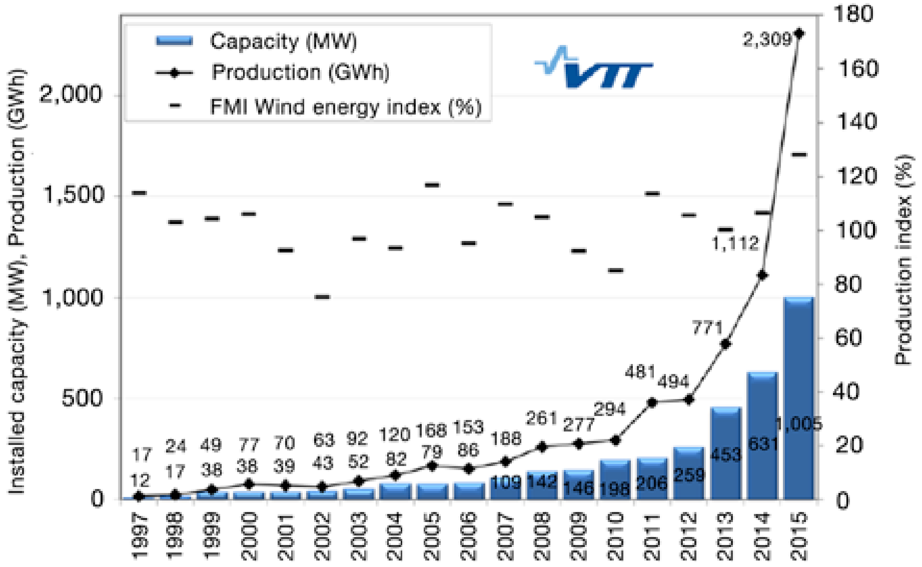

Figure 1. Development of wind power capacity and production in Finland

Six turbines were removed in 2015: two in Uusikaupunki (both 1.3 MW started in 1999), three in Oulunsalo (1 MW started in 2003) and a 1-MW turbine in Kotka (started in 1999) was replaced with 2.35-MW turbine. In Hailuoto, one of the turbines removed in 2014 was replaced with a 2-MW turbine in 2015.

The capacity of installed turbines ranges from 75 kW to 5 MW (average: 2.6 MW). About 7% of the capacity is from turbines originating from Finland, 41% from Denmark, 12% from Spain, 32% from Germany, 4% from France, 2% from South Korea, and 2% from the Netherlands, as shown in Figure 2. Seventy five percent of total wind capacity is from turbines with rated power of 3 MW or more, as shown in Figure 2. This development towards larger turbines is expected to continue in the near future.

Most of Finland's wind capacity is land-based. The first installations were on the coastal areas of Finland, but more inland sites have been developed and deployed during the last few years following the introduction of tall turbines with large rotors into the market (Figure 3).

The total capacity offshore is 24 MW. The offshore wind turbines are located mainly on small cliffs or artificial islands, being semi-offshore; so far only one is constructed on a caisson. The number of turbines is small because the guaranteed price is not sufficient to start offshore projects. Based on a competitive process, an extra investment subsidy of 20 million EUR (22 million USD) was granted in December 2014 to Suomen Hyötytuuli Oy to construct an offshore wind farm on the Finnish west coast with approximately 40-MW. Apart from this demonstration project, one larger offshore wind power plant (288 MW) received a building permit according to the water act, and six other offshore projects (almost 1,200 MW) have finished their environmental impact assessments.

### 2.3 National incentive programs

A market-based feed-in system with guaranteed price entered into force on 25 March 2011 in Finland. A guaranteed price of 83.5 EUR/MWh (90.9 USD/MWh) for 12 years is set for wind power; the difference between the guaranteed price and spot price of electricity will be paid to the producers as a premium. There was a higher guaranteed price level of 105.3 EUR/MWh (114.6 USD/MWh) until the end of 2015 to encourage early projects. The regulator, Energy Authority, is managing the system.

A three-month average spot price (day-ahead electricity market price at the Nordic market Elspot) will be the comparison price to determine the payments to the producers. Producers will be paid

**Table 1. Key National Statistics 2015: Finland**

| | |
|---|---|
| Total (net) installed wind capacity | 1,005 MW |
| New wind capacity installed | 374 MW |
| Total electrical output from wind | 2.3 TWh |
| Wind-generated electricity as a % of national electric demand | 3% |
| Average national capacity factor* | 32% |
| Target: | 6 TWh/yr for 2020,<br>9 TWh/yr for 2025 |

*For wind farms operating for the entire year
Total installed new capacity 379 MW including 5 MW dismantled

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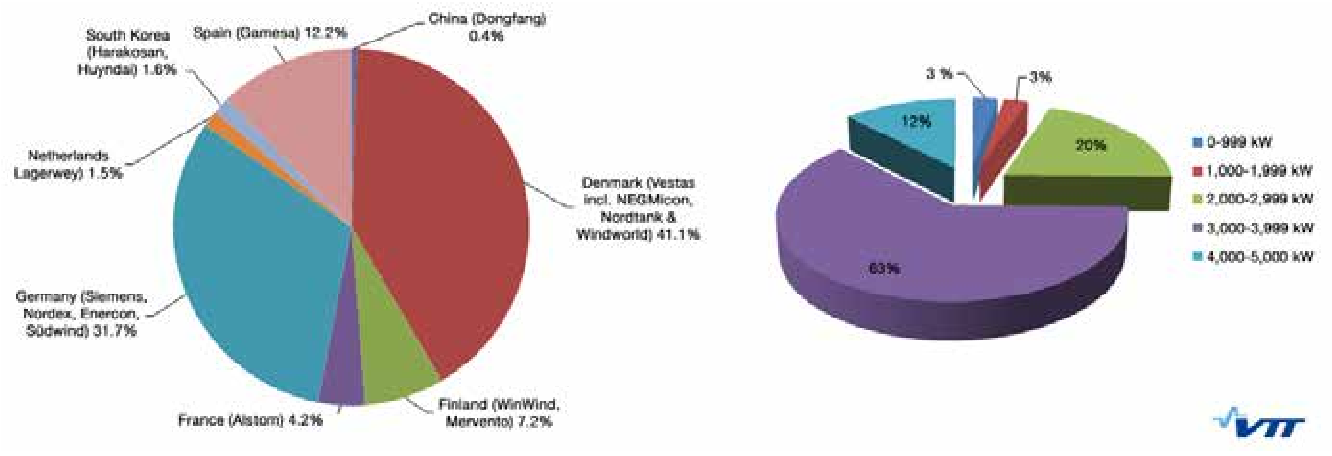

Figure 2. Turbine types (left) and turbine sizes (right) in Finland

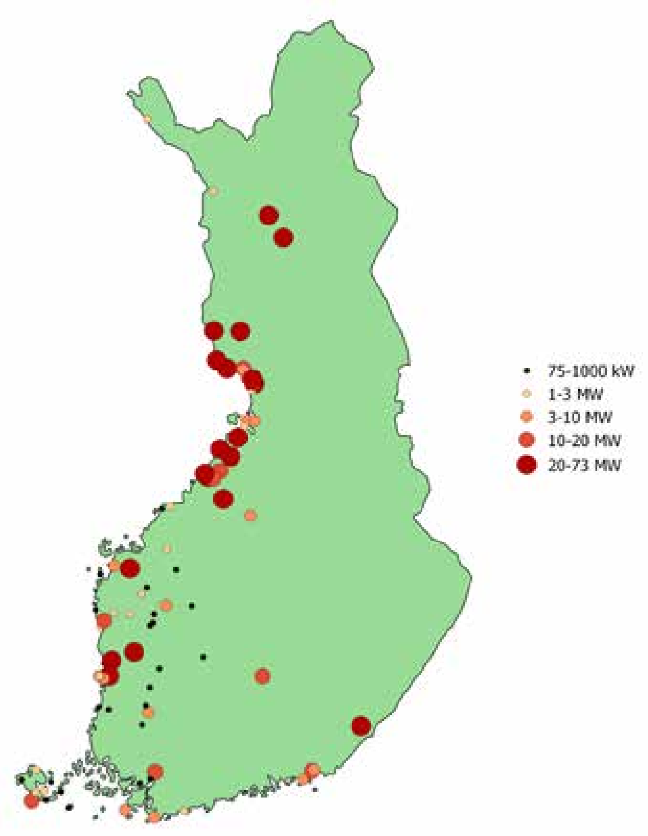

Figure 3. Wind power plant sites in Finland

the guaranteed price minus the average spot price, after every three-month period. Should the average spot price rise to above the guaranteed price, the producers will get this higher price. Should the average spot price drop to below 30 EUR/MWh (33 USD/MWh), the producers would only get a production premium based on the 30 EUR/ MWh (33 USD/MWh) level. If the price is zero in any hour, the producers will not be paid for that hour—this is to incentivize turbines shutting down to help the power system in cases of surplus power production. So far, zero price events have only happened in Denmark with larger wind shares than are planned for Finland. Wind power producers will also be responsible for paying the imbalance fees from their forecast errors. This has been estimated to add 2.0 EUR/MWh to 3.0 EUR/MWh (2.2 USD/MWh to 3.3 USD/MWh) to the producers if they use a weather forecast based prediction system for the day-ahead bids to the electricity market.

If the emission trading of fossil fuel prices raises electricity market prices, the payments for this subsidy will be reduced. However, so far the electricity prices have been low and the cost for the subsidy, recovered by taxes, has been quite high per MWh. In 2015, the total amount paid as a subsidy was 143.7 million EUR (156.3 million USD) for the 2 TWh in the subsidy scheme, as the higher guaranteed price was paid and market prices were low (average 30 EUR/MWh; 33 USD/MWh).

In May 2015, the new government announced a cut to the subsidy scheme, but before the new law was passed, the quota for 2,500 MVA was filled with applications. If all the projects accepted in the quota will be built in the allowed two-year limit, the original target for 2020 may be fulfilled by 2018; the 2,500 MVA target correlates to approximately 2,000 MW. Taking into account that there may be projects that fail to be built and not all projects experience excellent wind resources, the generation will be more like 4.5–5 TWh/yr. By the end of 2015, 1,038 MVA had been accepted to the guaranteed price system and 1,025 MVA had a quota decision. Once the quota is filled for the first time, there will be no more projects taken in the quota even if some projects are not built.

A new subsidy scheme fulfilling the new EU guidelines for technology neutrality and auctioning is currently planned by a working group in the ministry. The working group report will be published in May or June 2016. The working group updating the Energy and Climate strategy will decide on the 2030 renewable energy targets and the support mechanisms for reaching the target. The Energy and Climate strategy will be published in December 2016.

There is no special subsidy for offshore wind power. An offshore wind power plant demonstration subsidy of 20 million EUR (22 million USD) was granted in December 2014 for the Hyötytuuli project in Pori (about 50 MW).

### 2.4 Issues affecting growth

In the near future, one challenge will be the continuation and content of the subsidy system after the current system, where the quota is already filled for the 2,500-MVA target. All projects in the planning process are anxiously waiting for information on the next system, and whether it can be started before 2018 to reduce the waiting time.

The main challenges to growth during the last few years have been related to **planning and permitting**. The process with the environmental impact assessment is considered lengthy by developers and also varies regionally. Land use and building laws changed in 2013 to enable easier permitting for industrial sites. Also, there is an on-going practice in all regional plan updates to add sites for wind power plants by the authorities. This will help in permitting future wind power projects. However, some local communities have declined building permits for sites marked in regional plans.

**Noise**, especially low-frequency noise, has become an issue at many sites. New regulations published by the Ministry of Environment in 2012 required lower noise limits than the building law (by 5–10 dB). This is challenging in many sites, especially the night-time limit of 35 dB near summer cottages. The Ministry of Environment published guidelines on modeling and measuring the wind turbine noise in February 2014. If there is a possibility for especially disturbing noise emission, a 5-dB increase to modeled values can be made. A governmental decree on noise limits was given in fall 2015.

**Public acceptance** of wind power is generally high. According to annual surveys, 81% of Finns see the need to increase the wind production capacity. However, local resistance to the projects has sometimes slowed down project development. The Finnish Wind Power Association has published guidelines of best practices for project development to improve local acceptance of the wind farm projects. A recommendation for a compensation scheme has also been published by the Finnish Wind Power Association to improve local acceptance, including the land owners that are neighboring a wind power plant site.

Impact of wind turbines and wind farms on **radar** systems stopped permitting processes in 2010. Procedural and modeling tools were set up to help the Ministry of Defense assess radar impacts, after which a majority of the sites have been released to further development. A working group investigated necessary changes to radars for two regions (northern coast and southeastern Finland). A compensation scheme to invest in new radar and to recoup costs from the developers was developed for the former case.

**Safety distances** required from roads, railways, and aviation routes has limited development. The Ministry of Traffic and Communication has acted to relieve limitations by reducing the required distance between wind turbines and roads from 500 m to 300 m. Flight barrier limitations are now only 15 km along the runway (previously 30 km) and 6 km across runway direction (previously 12 km). In some areas the height of the turbines is limited. The rules for flight obstruction lights on nacelles of turbines have been relieved, enabling fewer disturbances to local inhabitants.

One challenge for public acceptance is related to the premium paid over the electricity market price to wind power producers. The concern is over the domestic content in the value of a wind farm over the lifetime. There may also be challenges regarding the unexpected effects of turbine's real lifetime, turbine reliability, O&M cost, in-cloud icing of taller and larger turbines, etc. on the economic performance of wind farms over their lifetime.

## 3.0 Implementation

### 3.1 Economic impact

Direct and indirect employment from development and O&M is increasing, with 2,200 jobs reached in 2015. The technology sector is strong in Finland, employing 2,000–3,000 people. According to the Technology Industry wind power suppliers group and the Finnish Wind power association, the employment figures could double by 2030 if a stable political environment for the deployment of wind energy is maintained.

### 3.2 Industry status

All in all, there are more than 100 companies in the value chain from development and design of wind farms, to O&M and other service providers.

#### 3.2.1 Manufacturing

More than 20 technology and manufacturing companies are involved in wind power in Finland. Most of the companies are in planning and construction of wind farms in the domestic market. After the bankruptcy of WinWind, only Mervento remains as a domestic turbine manufacturer, offering a 3.6-MW, direct-drive turbine, especially designed for near-shore and offshore applications.

Several industrial enterprises have developed important businesses as world suppliers of major components for wind turbines. For example, Moventas Wind is the largest independent global manufacturer and service provider of gears and mechanical drives for wind turbines. ABB is a leading producer of generators and electrical drives for wind turbines and wind farm electrification, both land-based and offshore. The Switch supplies individually tailored permanent-magnet generators and full-power converter packages to meet the needs of wind turbine applications, including harsh conditions. In addition, materials such as cast-iron products, tower materials (SSAB, formerly Rautaruukki), and glass-fiber products (Ahlstrom Glasfiber) are produced in Finland for the main wind turbine manufacturers. Sensors especially for icing conditions are manufactured by Vaisala, and Labkotec. Foundation solutions for ice infested waters are developed by many companies, like Technip. Peikko is offering foundation technologies based on modular components. A growing number of companies offer operation and maintenance services in Scandinavian and Baltic markets, including Bladefence, JBE Service, Wind Controller, and Airice.

#### 3.2.2 Ownership and applications

Many newcomers have entered the Finnish wind power market. They include both domestic and foreign investors and project developers. Power companies and local energy works are active in

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building wind power and green electricity is offered by most electric utilities. The supply of used turbines has encouraged some farmers to acquire second-hand turbines, but the wind resource is limited inland at heights below 100 m due to forested landscape.

The first semi-offshore projects were built in 2007. The total capacity offshore is 24 MW. Hyötytuuli Oy was granted a demonstration subsidy for a 50-MW offshore demonstration wind farm, which will be located outside Pori on the west coast. The wind farm is planned to be constructed in 2017.

### 3.3 Operational details

New projects are being built in the forested inland locations using towers up to 140 m high. High towers and new designs with larger rotors provide considerably higher capacity factors than previously installed in Finland, from 20–25% up to 30–40%. The average capacity factor from wind farms operating the whole year (48 farms) was 32% (calculated as total generation 1,615 GWh divided by total capacity 573 MW and total hours 8,760 hours). The average individual wind farm capacity factor was 28% in 2015. This last year, 2015, was windier than average: the wind power production index ranged from 105% to 135% in different coastal areas in Finland, averaging 128%.

### 3.4 Wind energy costs

All wind energy installations are commercial power plants and have to find their customers via a free power market. In most cases, an agreement with a local utility is made that gives market access and financial stability. The average spot price in the electricity market, Nordpool, was 30 EUR/MWh (33 USD/MWh) in 2015 compared to 36 EUR/MWh (39 USD/MWh) in 2014. Wind power still needs subsidies to compete, even on the best available sites. The guaranteed price, feed-in premium for wind energy fits the Nordic electricity markets, as the producers will sell their energy through the market as any other producers, and account for the balancing costs for their production.

## 4.0 R, D&D Activities

### 4.1 National R, D&D efforts

The Finnish Funding Agency for Technology and Innovation (Tekes) is the main public funding organization for research, development, and innovation in Finland. Tekes' funding for wind power in the last seven years is presented in Figure 4. Tekes granted 1.7 million EUR (1.9 million USD) in wind power R&D projects in 2015. Since 1999, Finland has had no national research program for wind energy, but individual industry coordinated projects can receive funding from Tekes. Ongoing wind power related R&D projects are mostly industrial development projects. The main developed technologies included power electronics, generators, permanent-magnet technologies, gearboxes, wind turbines (large and small ones), sensors, blade manufacturing, foundry technologies, construction technologies, automation solutions, offshore technology, and services.

VTT Technical Research Centre of Finland (VTT) is developing technologies, components, and solutions for large wind turbines. An icing wind tunnel for instrument and material research and testing in icing conditions began operation in 2009. Industrial collaboration in the development of reliable and cost-efficient solutions for drive trains for future wind turbines continued. Several technical universities, such as Aalto, Lappeenranta, Tampere, and Vaasa, also carry out R&D projects related especially to electrical components and networks.

### 4.2 Collaborative research

VTT has been active in several international projects in the EU, Nordic, and IEA frameworks. In the Nordic Energy Research projects Offshore DC and IceWind, VTT studied cost benefits of offshore grids in the Baltic Sea, losses in generation due to icing, as well as the smoothing effect of Nordic wide wind power generation and forecast errors. VTT is a founding member of the European Energy Research Alliance (EERA) and participates actively in the joint programs in wind energy and smart grids. Finland is taking part in the following IEA Wind research tasks:

- Task 11 Base Technology Information Exchange (VTT)
- Task 19 Wind Energy in Cold Climates (OA, VTT)
- Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power (OA, VTT)
- Task 31 WAKEBENCH: Benchmarking of Wind Farm Flow Models (Numerola)
- Task 33 Reliability Data: Standardizing Data Collection for Wind Turbine Reliability, Operation, and Maintenance Analyses (VTT and ABB)
- Task 36 Forecasting for Wind Energy (Vaisala, VTT and FMI)

## 5.0 The Next Term

Approximately 400 MW of new capacity is anticipated for 2016 and up to 600 MW are anticipated for 2017. Currently there are 1,184 MVA accepted to the guaranteed price system and almost 1,000 MVA had a quota decision with two years' time to be built and begin operation. An offshore demonstration of roughly 50 MW is planned to be built in 2017 and has a reserved place in the quota. A huge number of projects are planned (12,900 MW) of which more than 2,400 MW are in the building permit process and 800 MW ready to be constructed. The new subsidy system currently planned by a working group in the ministry will determine how many of these projects will be realized.

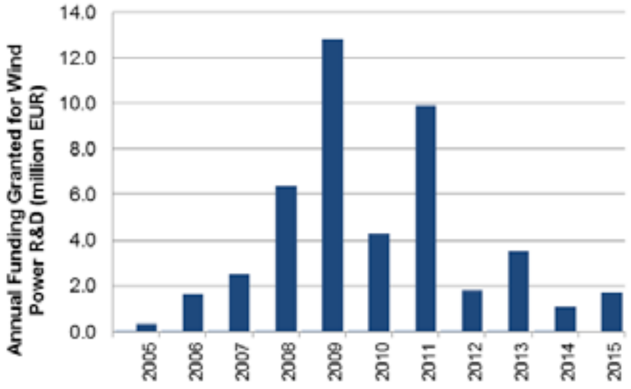

Figure 4. National R&D funding for wind energy related projects by Tekes

Overcoming the limits of cold climate is important to wind power development in Finland. The blade heating system developed at VTT is now in commercialization; a spin-off from VTT (Wicetec) started activities in 2014. Further research and development in this area will continue in 2016.

**References:**

Opening photo: Myllykangas wind power plant, Finland (Photo credit: Taaleritehdas)

The statistics for wind power in Finland can be found at www.vttresearch.com/services/low-carbon-energy/wind-energy/wind-energy-statistics-in-finland

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# 25 France

## 1.0 Overview

**Wind is the second largest renewable source of electricity production in France after hydroelectricity. Nearly 1 GW of wind capacity was installed 2015, leading to a total land-based wind capacity of approximately 10.3 GW. The amount newly connected in 2015 decreased from that of 2014, but shows a fairly high installation rate—greater than for 2011 to 2013. The yearly wind production was 20.2 TWh, representing almost 23% of the 88.4 TWh from renewable sources in France in 2015. Wind provided for 4.3% of the country's electricity demand and all renewables accounted for 18.7%.**

**The sustained rate of installation reflects the impact of recent regulatory changes such as the confirmation of the feed-in tariff (FIT) and simplification of administrative procedures. During 2015, the Energy Transition for Green Growth Act was adopted. This law ensured the stability of the support mechanism for wind and introduced several administrative simplification measures that should foster the development of renewables and wind.**

**Along with the preparation of a third round of fixed offshore wind tenders, the French government also launched a dedicated call for pilot floating wind farm projects.**

**With respect to contributions to IEA Wind in 2015, 16 French organizations participated in several R&D tasks. France hosted the 76th IEA Wind Executive Committee (ExCo) meeting at IFP Energies nouvelles (IFPEN) in Rueil-Malmaison.**

## 2.0 National Objectives and Progress

The directive 2009/28/CE set a 23% target for the contribution of renewables to final energy consumption by 2020. This objective was translated since 2009 into French law through the multiannual programming of investment, the "Programmation Pluriannuelle des Investissements" (PPI). The PPI defined targets for the capacity of power generation by primary energy source and, where appropriate, by production technology and geographic area. The PPI encompassed both the "Grenelle de l'environnement" and the adoption of the European Energy Climate of December 2008. The PPI defines the national objectives of energy policy (security of supply, competitiveness, and environmental protection) in terms of development of electricity production by 2020. It contributes to the implementation of non-$CO_2$-emitting energy sources including renewable or nuclear.

The Energy Transition for Green Growth Act was adopted on 18 August 2015 and set new trajectories for renewables in France. Specifically, it aims at defining long-term objectives such as:

- Reducing GHG emissions by 40% between 1990 and 2030,
- Accelerating energy efficiency and reducing the primary energy consumption by 50% between 2012 and 2050,
- Increasing the share of renewable energy sources to 32% of the final energy consumption in 2030 and 40% of the electricity production by 2030, and
- Diversifying electricity production and reducing the share of nuclear power to 50% by 2025.

For 2015, renewables represented 18.7% of the electricity demand, with wind being the second largest source after hydro. This number was lower than 2014 because consumption increased by approximately 2% while hydro decreased by 14% due very low rainfalls during the year. In order to set targets for 2018 and 2023 for each energy source, work to define the the Pluriannual Energy Program (Programmation pluri-annuelle de l'Energie (PPE)) started during the last quarter of 2015 and is ongoing.

### 2.1 National targets

For renewable energy, the PPI provides the following development targets by 2020:

- 25,000 MW of wind energy, specified as 19,000 MW land-based and 6,000 MW offshore
- 5,400 MW of solar energy
- 2,300 MW of biomass
- Additional 3 TWh/yr and 3,000 MW peak capacity for hydroelectricity
- 100 MW of installed wave, tidal, and floating wind, with between 200 and 2,000 MW of ongoing projects, depending on the outcome of the first pilot farm projects and price levels

The development of renewable energy aims to increase production to offset the equivalent of 20 million metric tonnes of oil.

The Energy Transition for Green Growth Act was adopted in its final version in August 2015. The Act defines long-term objectives in the framework for transitioning toward a low-carbon economy and energy system and it aims to define new policy tools. It addresses several aspects including energy efficiency, renewables deployment, and the future of nuclear energy. The Act defines several targets in terms of greenhouse gas emissions, primary energy consumption, share of renewables, and share of nuclear in electricity production. New targets for each renewable energy source will be defined in the PPE when finalized. Current trajectories for 2018 and 2023 scenarios were updated 24 April, 2016 as follows:

By the end of 2018:

- 15 GW of land-based wind
- 0.5 GW of fixed offshore wind
- 10.2 GW of solar energy
- 25.3 GW of hydroelectricity

By the end of 2023:

- Between 21.8 and 26 GW of land-based wind
- 3 GW of fixed offshore wind, with between 0.5 and 6 GW of ongoing projects, depending on the outcome of the first projects and price levels
- Between 12 and 18.2 GW of solar energy
- Between 25.8 and 26.05 GW of hydroelectricity

### 2.2 Progress

In France, the rate of installation of wind turbines increased between 2007 and 2010, with yearly figures above 1,000 MW, followed by a significant decrease from 2011 to 2013 and a positive 2014 year. With nearly 1 GW of incremental capacity installed, 2015 was a good year in terms of installation rate, leading to a total land-based wind capacity of approximately 10.3 GW (see Figure 1).

The increase in the rate of installation reflects the impact of the recent regulatory changes such as the confirmation of the FIT after EU validation and the simplification of administrative procedures. This led to a total annual production of 20.4 TWh, a large portion of the 88.4 TWh that renewables produced in 2015. After hydroelectricity, which represents approximately 60% of renewables production, wind is the second largest contributor. In the meantime, coal electricity generation decreased by 1.5 GW and now representing 2.3% of the installed capacity.

In 2015, wind and all renewables accounted for 4.3% and 18.7% of electricity production respectively. According to the transmission system operator in France, the electricity consumption in France amounted to 476.3 TWh, which was 2% above the 2014 figure, but approximately at the same level as years 2011 to 2013. Except in 2014, which benefited from quite favorable meteorological conditions, electricity consumption has been fairly stable in France due to the evolution of the economic structure as well as consumption moderation policies. Despite the encouraging activities during year 2015, a more rapid increase of the installation rate is needed to reach the 2018 PPI target of 18 GW of land-based installed wind capacity.

### 2.3 National incentive programs

In 2014, the French government confirmed the support mechanism for land-based wind, which was also validated by the European Commission. As a result, 2015 gave a more precise view on the future of support mechanisms for wind and other renewables. The Energy Transition for Green Growth Act introduced new funding mechanisms for renewables, introducing a so-called "Complément de rémunération" (Feed-in Premiums), which will be granted as a premium in addition to the market price at which generators sell their electricity directly in the market. However, the law does not apply to facilities that requested power purchase agreements prior to 1 January 2016. In addition, land-based wind turbines will benefit from a transition period that allows electricity producers to choose between the previous FIT system and the new Feed-in Premiums system. This transition period will extend at least to 2018, allowing both systems to exist in parallel. Stakeholders were consulted to finalize the Feed-in-Premiums support scheme and to provide the

**Table 1. Key National Statistics 2015: France**

| | |
|---|---|
| Total (net) installed wind capacity | 10,308 MW |
| New wind capacity installed | 932 MW |
| Total electrical output from wind | 20.2 TWh |
| Wind-generated electricity as a % of national electric demand | 4.3% |
| Average national capacity factor | 24.3% |

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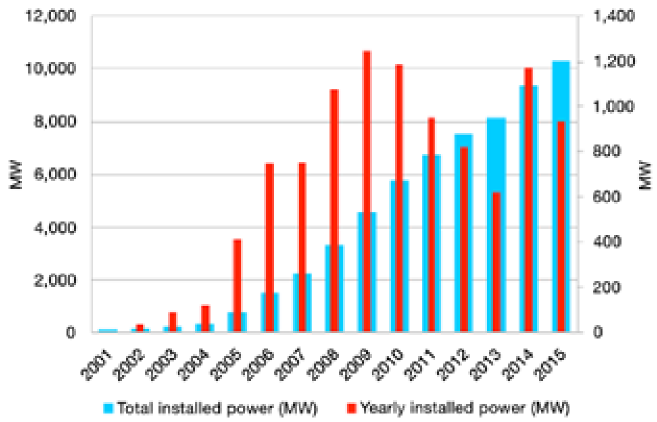

Figure 1. Total and yearly installed wind power in France 2001–2015

European Commission with a French-shared position in the context of the publication of the new European state aids guidelines. The decree was published in May 2016.

The FIT that remains in place consists of a fixed amount of 82 EUR/MWh (89 USD/ MWh) for the first ten years of operation, followed by an additional five years of purchase at a level dependent on the average production hours during the first ten years. Specific regulations (FIT level and conditions) were also defined for wind turbines installed in cyclonic areas in French overseas territories.

Offshore wind development has been directed through two calls to tender for the development of projects in predefined dedicated areas for a predetermined capacity. Grid connection was systematically guaranteed for each tender area. The selection of winning consortia was made on the basis of several criteria, including a proposed level of electricity FIT. A third round of tenders is being prepared by the French administration, in consultation with all stakeholders, and may include a possible evolution of the FIT for such future projects. Stakeholder engagement aims to improve the tender process, along with reducing the levelized cost of energy of such projects.

Along with this preparation work, a call for pilot farms of floating wind turbines was launched in 2015. It targets the development of pilot farms with 3 to 6 wind turbines and power equal to, or larger than, 5 MW in four designated areas (one in Brittany and three in the Mediterranean Sea). Pilot farms are expected to run for up to 20 years and will benefit from a double funding mechanism combining both a FIT and a direct partial funding of capital expenditures. This call closed in April 2016 with results expected after the summer.

### 2.4 Issues affecting growth

The Energy Transition for Green Growth Act confirmed an ongoing trend for simplification of the permitting and licensing process and introduced new measures:

- Suppression of the "Wind Development Areas" (Zones de Développement de l'Eolien or ZDE) and of the so-called rule of the five turbines (defining a minimum number of wind turbines per installation), as part of the French law for energy transition voted April 2013,
- Creation of specific support mechanisms and regulations were also adopted to foster the installation of wind turbines in the French overseas territories by the publication of a dedicated FIT,
- Authorization of installation of wind turbines in municipalities governed by the Coastline Protection Act (Loi Littoral) under certain conditions since August 2015,
- Extension of the validity of land-based wind environmental and construction permits permits up to 10 years since 2014,
- Approval and testing of a pilot authorization process ("one stop-shop" approach); testing was extended to the whole territory as of 1 November 2015 after being tested in several administrative regions—this should lead to an acceleration of administrative work needed for the development of land-based wind turbines,
- Reduction of deadlines for appeals within this single authorization process, and
- Creation of incentives for residents to acquire shareholdings in limited companies involved in local renewable energy projects

A revision of several technical constraints was adopted to facilitate the coexistence of wind turbines with radar, leading to updated administrative rules for the installation of wind turbines near meteorological radars. Furthermore, exchanges with the Defense and Administration for Civil Aviation (DGAC) could lead to improvements during 2016.

## 3.0 Implementation

### 3.1 Economic impact

According to the Syndicat des Energies Renouvelables (SER), the French industry employs approximately 10,000 people. Industrial players located in France are represented along most of the value chain of the wind sector, ranging from development and studies, component manufacture and delivery, engineering and construction, and operation and maintenance. This represents approximately 100 small-to-medium enterprises and 15 larger players.

The only wind turbine manufacturing facility in France was Vergnet, which produces "far-wind" wind turbines for cyclonic areas. Now, a French company, DDIS, is developing a patented technology for innovative direct-drive electrical machines. A large range of suppliers already exist such as Nexans for electric cables, Leroy- Somer for generators, Rollix for blade and yaw bearings, etc. Several small-to-medium enterprises are also providing advanced technologies such as LeoSphère, a leading lidar provider, METEODYN, METEOPOLE, providing service and software for wind resource assessment. This situation is currently evolving very fast, along with the development of a local offshore industry.

Within the PPE exercise, several forecasts are being made to assess possible job creation according to the various scenarios. Tentative figures show a potential ranging from 340,000 to 415,000 full-time equivalent jobs created by 2023 as the estimate of cumulative employment over 20 years.

### 3.2 Industry status

During 2015, a major evolution occurred in the French landscape of wind turbine manufacturers. In March, AREVA and GAMESA officially created ADWEN, a joint venture dedicated to designing and manufacturing large-scale offshore wind turbines. Alstom activities in wind were acquired by General Electric, which later confirmed that France would remain the headquarters for offshore wind.

Offshore farms tendered in 2011 and 2013 led both Alstom (now GE) and AREVA Wind (now ADWEN) to announce the installation of major industrial facilities in France. In 2014, Alstom inaugurated a new nacelle assembly factory near Saint-Nazaire, with plans for two new factories near Cherbourg (Normandy) for wind turbine towers and blades. The first commercial wind turbines to be produced are planned to be used for the Block Island project in the United States. ADWEN also confirmed plans to install several facilities near le Havre (Normandy). These important developments are expected to attract a strong network of local and European industry suppliers.

Other players are active in the development of foundations for offshore wind, such as STX France, which in 2014 delivered a substation for DONG and actively works to promote jacket solutions for offshore wind turbines. STX also launched an investment for new facilities for future substations and foundations in their Saint-Nazaire premises. The development of the floating wind projects has fostered the creation of French start-ups like Nenuphar, which is developing a vertical axis wind turbine for floating applications, and IDEOL, which is developing a concrete floater solution (see section 4.1).

In order to encourage the development of a local industry, a dedicated initiative called Windustry was launched with governmental support to encourage industrial development in the wind market, by strengthening the supply chain. It provides guidance and advice for companies seeking to enter the wind industry and diversify their activities. About 50 companies have been involved in the Windustry initiative so far and the initiative aims at creating 50,000 jobs by 2020.

### 3.3 Operational details

France was divided into 22 administrative regions until 2015 when a merger of these administrative regions led to a creation to 13 regions. From these 13 regions, two represent almost the half of the installed wind power. The leading regions, in terms of installed power, are are Les Hauts de France (ex Nord-Pas de Calais and Picardie) and Alsace-Lorraine-Champagne-Ardenne—with approximately 2,500 MW installed by the end of 2015. These two regions are located in the northern part of the country. In 2015, the same two regions represented more than 50% of the newly installed capacity, 276 MW and 216 MW respectively (see Figures 2 and 3). Other regions with good installed capacities are Languedoc-Roussillon-Midi-Pyrénées in the southwest and Brittany, illustrating the different wind dynamics in France.

France benefits from three different wind regimes, corresponding to the Mediterranean, the Atlantic Coast, and the North Sea/Channel ("Manche" area). This situation therefore leads to a non-homogeneous installation density of wind turbines, with very strong activity in the north and west. This translates into higher capacity factors in the north and south (Figure 4).

In terms of wind turbine suppliers, more than 75% of turbines installed in 2015 were from Enercon, Senvion, and Vestas. Looking at the whole installed capacity, Enercon, Nordex, Senvion, and Vestas hold approximately 75% cumulative market share.

Though the current wind turbine installations are located on land, offshore wind is considered to be a strategic sector and has been highly supported in the recent years. More precisely, two tenders were initiated in July 2011 and March 2013 to develop offshore wind farms. Four areas were defined for a total of approximately 2,000 MW in the first round and two others for a total of 1,000 MW in the second round (see Figure 5).

Eolien Maritime France, a consortium led by EDF EN and Dong Energy, was awarded the Fécamp, Courseulles-sur-Mer and Saint-Nazaire wind farms where the 6-MW GE-Alstom Haliade wind turbines will be installed, for a total of approximately 1,500 MW. Ailes Marines SAS, a consortium led by Iberdrola and Eole-RES, was awarded the Saint-Brieuc wind farm where ADWEN 8-MW wind turbines are expected, for a capacity of 500 MW. A consortium led by ENGIE, EDP Renewables, and Neon Marine was awarded the Tréport and Iles d'Yeu-Noirmoutier areas, where ADWEN 8-MW turbines are expected totaling nearly 1,000 MW.

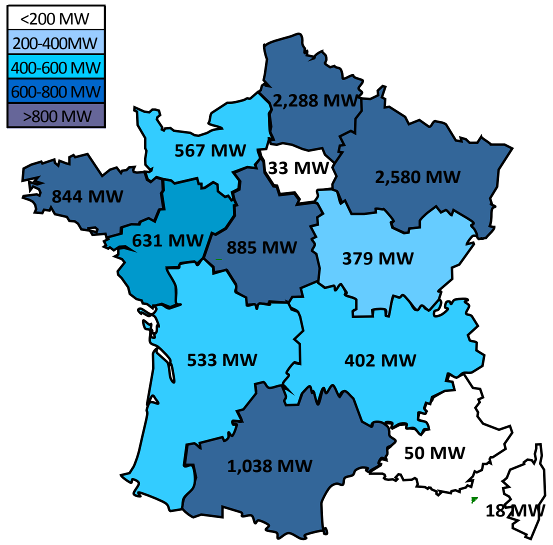

Figure 2. Total installed wind power per region

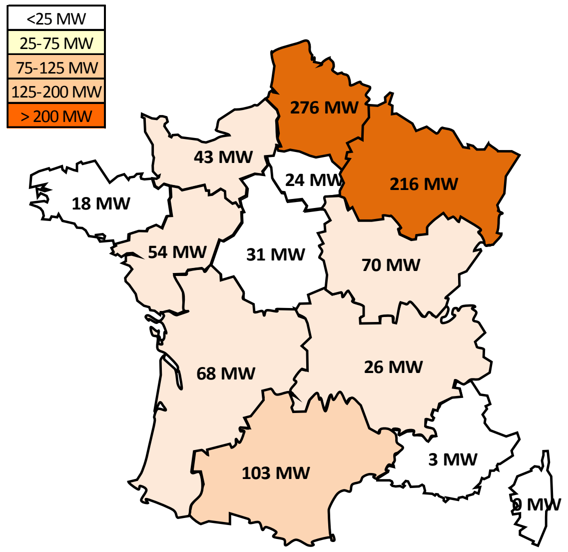

Figure 3. Installed wind power during 2015 per region

# 25 France

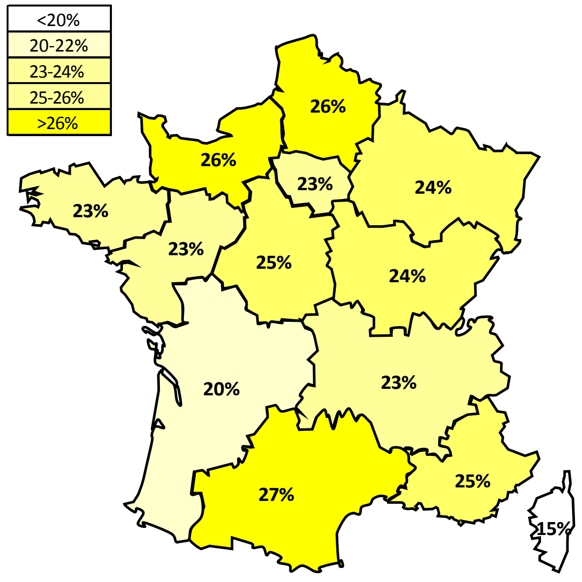

Figure 4. Capacity factors during 2015 per region (Source RTE)

## 4.0 R, D&D Activities

### 4.1 National R, D&D efforts

The development of offshore wind and large wind turbine technology has been a priority in recent years. The French Agency for Environment and Energy Management (ADEME) has been the driving funding agency for applied R, D&D projects. ADEME funds and administers three kinds of projects: PhD thesis, R&D projects for intermediate TRL, and the Programme des Investissements d'Avenir, dedicated to industrial projects, and funded by subsidies, reimbursable aids, and possibly equity. Wind energy R&D projects funded by ADEME cover resources assessment, radar compatibility, materials, and the study of biodiversity.

In the area of industrial demonstration projects, after a call for proposals in 2009 on ocean energies which included floating wind technologies, another call was launched and four projects awarded by ADEME in 2013. These four projects are:

1. The EOLIFT project (2013–2017), led by Freyssinet, proposes the development of innovative pre-stressed wind turbine concrete towers for high power (more than 3 MW) and tall height (more than 100 m), incorporating lifting equipment to avoid the need for high capacity cranes. The objective is to increase the speed of construction of wind farms and to reduce costs related to the tower and foundation by 15%. A demonstration is planned for a 3-MW wind turbine with a 120-m tower.

2. The JEOLIS project (2013–2017), led by Jeumont Electric, aims to develop a new hybrid generator to optimize the electric conversion chain of wind turbines. It is composed of generator with a winding on the rotor, whose performance is enhanced by a significantly reduced number of permanent magnets. A demonstration is on-going on a coastal 750-kW turbine. The project also targets the design of a 5–6 MW generator.

3. The EFFIWIND project (2014–2019), coordinated by the Adera and Canoe platform, is focused on the development of new thermoplastic materials for blades and nacelle housings. It aims to demonstrate the use of acrylic resins for these applications on offshore wind turbines. A set of blades will be produced and tested on a land-based wind turbine.

4. The Alstom Offshore France (AOF) project, coordinated by Alstom Renewable Power, is dedicated to the creation of industrial facilities in France for the production of the Haliade 6-MW offshore wind turbines. The project includes the creation of three industrial facilities near Saint-Nazaire and Cherbourg, one for the assembly of nacelles, one for manufacturing permanent magnet generators, and the third to manufacture blades.

Among the selected topics, floating wind technology was identified as a strategic area because France has a favorable situation for floating wind: local harbor facilities, and a local naval and offshore oil and gas industry capable of supporting this market. More precisely, three projects are currently under development for floating wind.

- The Vertiwind (2011–2017) project aims at developing an innovative vertical axis wind turbine technology designed by the start-up Nénuphar, Oceanide, Bureau Veritas, and IFP Energies Nouvelles. This project is associated with the EC FP7 INFLOW project, led by IFP Energies nouvelles, and is planned to qualify the technology. The project will be a first milestone to demonstrate the Twinfloat concept using contra-rotative vertical axis wind turbines.
- The SeeReed project (2013–2017), led by the DCNS Group and GE Alstom, covers the qualification of a semi-submersible lightweight floating wind energy platform equipped with the 6-MW Haliade turbine.
- The OceaGen project (2014–2017), led by IDEOL (a start-up located in the South of France) and Bouygues, aims at developing a concrete barge using the Damping Pool™ concept. A prototype was scheduled to be installed in 2015 on the SEM-REV test site off the Atlantic coast at Le Croisic.

Phase 2 of the VALEF project was carried out in the framework of France Energies Marines (Institute for Energy Transition). This project aims to provide adequate methodologies and validation data to ensure the accuracy of the software modeling the dynamic behavior of floating wind turbines. It includes several partners: ADWEN, Ecole Centrale Nantes, DCNS, EDF, IFP Energies Nouvelles, and INNOSEA.

During 2015, the SmartEole project was selected by the French National Research Agency (ANR). Led by Prisme Orléans, the main objective is to improve the energy production efficiency and lifespan of wind turbines through the development of lidar-based innovative control solutions. The project started in January 2015 and is scheduled for 3.5 years. It aims at demonstrating control strategies at different scales of wind turbines: blade, wind turbines, and farm. A first test campaign was carried out on a Maia Eolis site to acquire nacelle based, vertical, and scanning lidar measurements. Several experiments have also been carried out at the lab scale to test air jet active control.

### 4.2 Collaborative research

Along with several national projects, France is also active in several European projects, such as:

Figure 5. Results of first (in red) and second (in green) rounds of offshore tenders (Source: DGEC)

- The Spinfloat project, led by ASAH LM /EOLFI and Gusto MSC, which is based on a vertical axis wind turbine with pitched blades installed on a three-column, braceless, semi-submersible floater. This project also involves SSP Technology, a Danish blade manufacturer; Fraunhofer IWES the German Institute for Wind Energy, in charge of the drive train; GustoMSC, the Dutch designer of mobile offshore units; ECN the Dutch energy research Institute; and the Italian University Politecnico di Milano for wind tunnel testing.
- The INFLOW project, which is carried out in close relation with Vertiwind, addresses the demonstration phase of the latter project. It is led by IFP Energies nouvelles and also involves numerous partners from six European countries, including the Nenuphar Startup, EDF Energies Nouvelles, DUCO Vicinay Cadenas, VryHof Anchors BV, Fraunhofer IWES, DTU, and Eiffage Constructions Métalliques.

After joining IEA Wind in 2014, 16 French organizations including companies, RTO, SMEs, and laboratories have expressed interest in several tasks and started progressively contributing with very positive results. Participation includes: Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power, Task 29 Mexnext: Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models, Task 30 Offshore Code Comparison Collaboration Continued with Correlation (OC5), Task 31 WAKEBENCH: Benchmarking of Wind Farm Flow Models, Task 32 LIDAR: Lidar Systems for Wind Energy Deployment, Task 33 Reliability Data: Standardizing Data Collection for Wind Turbine Reliability, Operation, and Maintenance Analyses, and Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN). Participation in Task 30 helped the validation by IFPEN and Principia of the DeepLines Wind™ software used to model the dynamic behavior of fixed and floating offshore wind turbines which was commercialized in 2015.

During 2015, IFP Energies nouvelles hosted the 76th IEA Wind Executive Committee meeting at its premises in Rueil-Mamaison, and organized with LeoSphère, a demonstration of lidar technology, along with a workshop on floating wind initiatives in France.

## 5.0 The Next Term

After the adoption in 2015 of the Energy Transition for Green Growth Act, 2016 will see the definition of the future objectives for renewables through the PPE and adoption of a new scheme to support the development of renewables and wind for the coming years. The development of offshore wind is also expected to continue, with the announcement of a third round of tenders. The outcome of the call for pilot farms of floating wind turbines will also be known in 2016 and will undoubtedly strongly enhance the development and demonstration of this technology.

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Opening photo: Beau Regard (Photo credit: Maia Eolis)

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Authors: Daniel Averbuch, IFPEN Energies nouvelles, France; and Victoire Lejzerzon, Ministère de l'Environnement, de l'Energie et de la Mer (DGEC), France.

# 26 Germany

## 1.0 Overview

**German wind energy development in 2015 shows that land-based and offshore wind is of high importance for the success of the German Energy Transition. The share of renewable energy sources (RES) in Germany's gross electricity consumption continued rising in 2015, reaching 32% with 195 billion kWh. This represents an ongoing increase of more than 4.5% compared to the previous year (27.4% RES). Wind energy provided 44.9 % of all renewable energy generation in 2015, making it one of the most important renewable energy sources.**

**Regarding electricity generation by wind energy, 2015 was a year of exceptional increase for Germany: 87.98 billion kWh were fed into the grid by wind turbines. This represents an enormous increase of more than 50% in comparison to the previous year 2014 with 57.4 billion kWh.**

**Land-based wind is currently the most cost-efficient renewable energy technology for electricity generation in Germany. In 2015, net capacity of 3,535.77 MW was added, totaling a land-based capacity of 41,651.50 MW (with 25,982 wind turbines). This includes decommissioning measures for 253 land-based wind turbines totaling 195.18 MW of capacity which have only been partially rebuilt. Furthermore, the gross added capacity amounted to 3,730.35 MW (1,368 turbines) which includes 484 MW (176 turbines) of repowering.**

**Installed offshore capacity totals 3,294.90 MW with 792 wind turbines; this includes 2,282.40 MW added in 2015, more than tripling the capacity. Since 2014, offshore wind power of 1,037 MW was grid connected. An offshore capacity of 246 MW was erected but was not connected to the grid by 31 December 2015. Another 956 MW are under construction and the decisions for final investment have been made for an additional 865 MW. Consequently, the maximum grid connection capacity target of the German federal government of 7.7 GW by 2020 will be reached with confidence.**

**The capacity factors were up to 22.7% for land-based and 45.7% for offshore, both above the long-term average. The use of wind energy avoided 59.8 million tons of equivalent carbon dioxide emissions in 2015.**

**Concerning R&D activities within the ongoing German 6th Energy Research Program from 2011, the Federal Ministry for Economic Affairs and Energy (BMWi) provided 91.1 million EUR (99.1 million USD) of funds for 110 new research projects in 2015. Land-based wind energy trends toward bigger rotor diameters continue. Research and development activities focus on this, as well as on the impacts of bigger rotors on gear boxes and bearings. Furthermore, to keep transport costs low, modularized components for land-based wind turbines are also being investigated [1, 2, 3, 4, 5, 13].**

## 2.0 National Objectives and Progress

### 2.1 National targets

According to its 10-point energy agenda, the German federal government revised the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG) in 2014. Still, the German federal government is adhering to the ambitious development goals for the share of renewable energies accounting for 40% to 45% of the gross electricity consumption by 2025, 55% to 60% by 2035, and 80% or more by 2050. These goals are implemented by the EEG, which is the key instrument that will enable Germany to meet these targets in an orderly manner.

In the future, the level of funding shall no longer be fixed by the state. Rather it will be determined on the market using competitive, tendering procedures for land-based and offshore wind, as well as for other renewable energy sources like photovoltaics. The EEG amendment took place in 2016 and will go into effect in 2017. To keep a variety of stakeholders, special tender rules are in place for citizens' wind projects and 5% of the tenders will be open to other European Union member states.

Wind energy for both land-based and offshore projects will be affected by the amendment. Land-based wind projects permitted by the end of 2016 and in operation by the end of 2018 are to remain in the current EEG 2014 feed-in tariff system, as will wind turbines with up to 750 kW capacity and pilot turbines (prototypes and R&D turbines) totaling up to 125 MW per year. Offshore wind projects that are in operation at the end of 2020 will also remain in the EEG 2014 feed-in tariff system. All other projects will be subject to the 2016 EEG amendment.

The annual additional new land-based wind capacity will be yearly put up for tender. The first tender is scheduled for 2017 and additional tenders will follow until 2019 (2.8 GW in 2017–2019, 2.9 GW as of 2020). The maximum bid at tender allowed will be 0.07 EUR/kWh (0.076 USD/kWh) at the standard 100% reference site, fixed for 20 years. To compete fairly and ensure a geographical spread of developments across Germany, bids for wind farms at locations with widely varying wind conditions will be adjusted through a reference earnings model.

Calls for bids will be issued in 2017 for two offshore tenders, with 1.55 GW capacities each and delivered between 2020 and 2024. These are for projects that already have a license and have reached a certain level of development. The draft EEG amendment plans for 7.7 GW of offshore wind capacity to be installed in German waters by 2020, a significant increase compared to the previously projected 6.5 GW. The 15 GW target to be reached by 2030 remains unchanged [6, 7, 8, 17, 18].

### 2.2 Progress

As shown in Figure 1, once again Germany made immense progress toward reaching its renewable energy targets with a record net wind capacity added in 2015. Wind energy contributed 14.7% of the total electricity demand, accounting for nearly half of the renewable energy generation sources in Germany. Offshore wind energy made exceptional progress in 2015.

More than half of the adjusted German offshore wind target (7.7 GW by 2020) was reached by the end of 2015, counting 4,497 MW of installed and grid-connected wind turbines, turbines that were erected but not yet grid-connected, and turbines under construction [1, 3, 4, 5, 7, 9, 13].

### 2.3 National incentive programs

With the revision of the EEG in 2014, the major national incentive program in 2015 is as follows:

For wind turbine installations operating after 1 August 2014, the land-based basic value for the feed-in-tariff (FIT) is 49.50 EUR/MWh (53.86 USD/MWh) with 89.0 EUR/MWh (96.83 USD/MWh) as the initial value for the first five years of operation, amendable in duration by comparison with a reference yield. A yearly target of 2.4–2.6 GW of added land-based wind energy capacity serves as "breathing cap," only counting the net increase of wind energy capacity per year and forms a yearly digression of the FIT accordingly.

For offshore, the initial FIT is 154.0 EUR/MWh (167.55 USD/MWh) within the first 12 years (amendable in duration based on

**Table 1. Key National Statistics 2015: Germany**

| | |
|---|---|
| Total (net) installed wind capacity | 44,946.40 MW |
| New wind capacity installed | 5,818.17 MW |
| Total electrical output from wind | 87.98 TWh |
| Wind-generated electricity as a % of national electric demand | 14.7% |
| Average national capacity factor | 22.7% (land-based)<br>45.7% (offshore) |
| Target: | Land-based: 2,400–2,600 MW net increase per year,<br>Offshore: 7,700 MW (2020) and 15,000 MW (2030) |

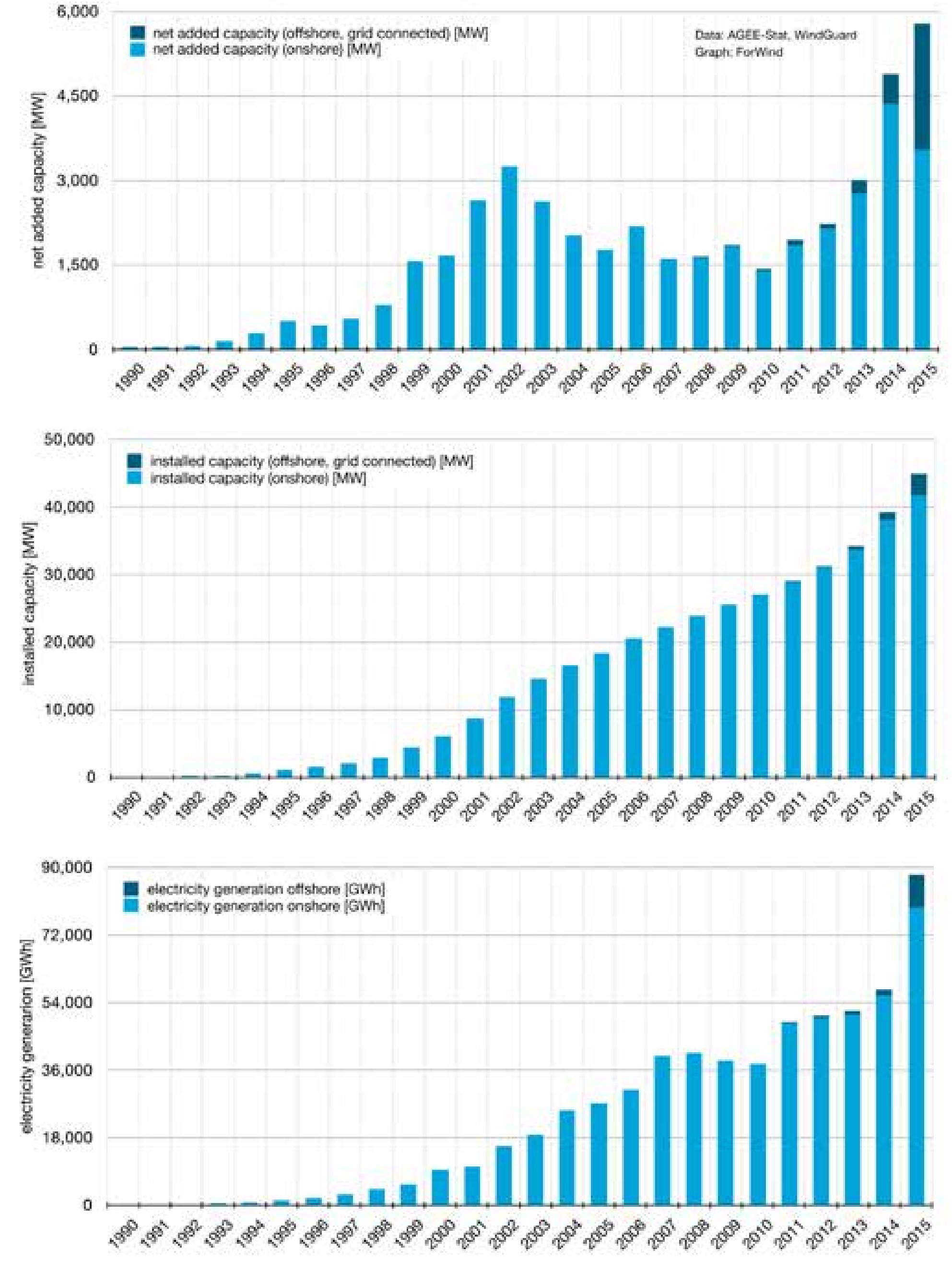

Figure 1. Net added and total installed capacity and electricity generation in Germany in 2015 [3, 4, 5]

water depth and distance from shoreline, see base model) and up to 194.0 EUR/MWh (211.07 USD/MWh) within the first eight years corresponding to the compression model ("Stauchungsmodell"). Afterwards, the FIT goes back to 39.0 EUR/MWh (42.43 USD/MWh).

Wind turbine operators have to merchandise the produced electricity directly if the capacity is above 500 kW (or 100 kW from 2016 on). For wind turbines rated above 3 MW, operators get a gliding market premium which includes a management premium. The premium can go near zero under special market conditions such as a negative price at the European Power Exchange Spot (EPEX) for more than six hours. This adjustment will be valid until 2017. According to the EEG amendment, from 2017 on, the German federal government will manage the reimbursement rates via tendering procedures for land-based and offshore wind as well as for other renewable energy sources like photovoltaics, as described in section 2.1 [6–11, 17, 18].

### 2.4 Issues affecting growth

Political announcements regarding the EEG amendment dominated 2015. The amendment will include tenders in combination with the existing FIT and will therefore affect the future growth of wind energy. Added land-based capacity in 2015 was not as strong as would have been expected due to the announced changes in regulations.

The immense offshore added capacity is most attributable to wind turbines that were erected in prior years and connected to the grid in 2015. Nevertheless, 249 of the 792 offshore wind turbines were erected and grid-connected in 2015. Germany has 13 offshore wind farms in operation including the nine newly installed offshore wind farms.

For land-based wind, the possible impacts of wind turbines on radar navigation devices still play an important role in Germany. Omni-directional radio beacons (DVOR/CVOR) are affecting more than 1,000 projects with a capacity of nearly 4 GW. To find out how mechanisms, tools, or equipment can help mitigate the problem that wind turbines cause for radars, an IEA Wind Topical Expert Meeting (TEM) was hosted by the Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR in late 2015. Representatives from eight countries attended this TEM [3, 4, 6, 9, 13, 16, 17, 18].

## 3.0 Implementation

The net added capacity of grid-connected wind power peaked in 2015 with 5.82 GW. A large share of which—2.28 GW—is coming from the successful implementation and connection of offshore wind farms in the Northern and Baltic Sea. After crossing the 1-GW offshore threshold in 2014, Germany's grid connected offshore wind power now totals 3.29 GW, representing almost 30% of all European offshore wind capacity [12]. Figure 2 shows the status of German offshore wind energy projects in early 2016.

Although this is a major success for the offshore wind industry, it has to be noted that a substantial portion was due to delayed grid connections, i.e., offshore wind turbines which were installed in 2014 but came online in 2015.

The strong growth in net added capacity, especially with good offshore wind conditions and a relatively good wind year for 2015 is visible in the energy provided by wind. With an increase from 57.36 TWh in 2014 to 87.98 TWh in 2015, almost 15% of the gross German energy consumption was covered by wind energy, making it the most important renewable energy source (45% of all renewable electricity generation). As such, greenhouse gas emissions were reduced by approximately 60 million tons of $CO_2$ equivalents [5].

Net added capacity of land-based wind energy is distributed unevenly throughout Germany. Due to wind conditions, the majority of newly added wind turbines were installed in the northern or central states. However, the amount of wind energy capacity in the southern states is growing too. Top players are still Lower Saxony for installed capacity (8.6 GW) and Schleswig-Holstein for added capacity (0.89 GW). The latter is driven by Schleswig-Holstein's good wind resources, which can also be seen in the average hub heights of their newly added turbines. While the other 15 German states installed turbines with average hub heights significantly more than 100 m (German average 123 m), the hub height average in Germany's most northern state is only 96 m.

### 3.1 Economic impact

Investments in renewable energy technologies totaled 14.5 billion EUR (15.78 billion USD), 66.5% of which was related to wind energy. With investments of 4.5 billion EUR (4.9 billion USD) for offshore and 5.2 billion EUR (5.66 billion USD) for land-based, both wind energy sectors have been almost equally important. In addition to this turnover, wind energy created economic impulses of 1.9 billion EUR (2.07 billion USD) (0.2 / 0.22 offshore, 1.7 / 1.85 land-based) by the operation of wind turbines and wind farms [5]. Thus while the investment costs increased compared to the previous year, the operational costs stayed the same, showing that the operation of wind energy is becoming more efficient.

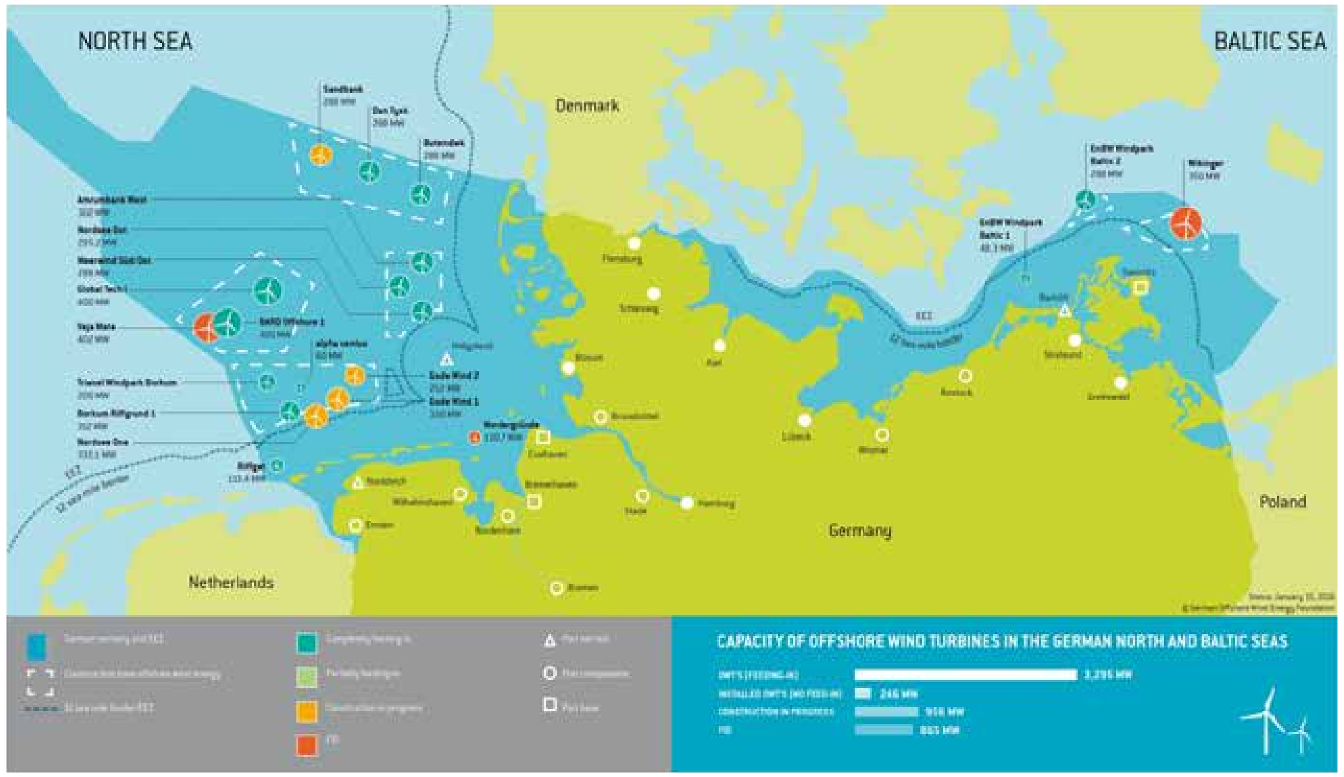

Figure 2. The status of German offshore wind energy projects (Courtesy of the German Offshore Wind Energy Foundation) [3]

Employment in the wind energy sector continued at a high level with 150,000 people, compared to 149,200 in 2014. In 2015, Siemens announced plans to set up a new production facility in Cuxhaven. Production will start in 2017 and up to 1,000 new jobs will be created, flanked by additional jobs due to secondary effects at sub-suppliers [12].

### 3.2 Industry status

In 2015, the German wind energy market was supplied by 11 original equipment manufacturers (OEMs). While the offshore market is divided by three OEMs (Siemens, Adwen, and Senvion), the land-based market is a bit more diversified. As in previous years Enercon (37%) is heading the market, followed by Vestas (20.8%), Senvion (17.9%), Nordex (11.7%), and GE (7.4%) [4].

In previous years, larger players had to file for bankruptcy or left the wind energy business voluntarily, but 2015 was a solid year in this respect. However, consolidation processes within the wind energy sector are ongoing and two new mergers were announced in 2015. Nordex announced plans to acquire the Spanish wind turbine manufacturer Acciona Windpower in order to form a new global player. The French company Areva and the Spanish manufacturer Gamesa formed a joint venture under the brand of Adwen, which will target the global offshore market. Early in 2016, rumors hit the news that Siemens is planning to acquire Gamesa. Regardless of many details yet to be clarified, such as an agreement with Areva, this agreement would accelerate the process of consolidation even further.

Siemens officially announced that it will invest 200 million EUR (218 million USD) in the construction of a new offshore wind turbine production facility in the city of Cuxhaven. It plans to build next generation nacelles in that facility. This will be Siemens's first wind energy related facility in Germany and will be the biggest investment in a German production facility in recent history. The 24 soccer field-sized site (170,000 $m^2$) will be located directly at the harbor of Cuxhaven, avoiding costly on-land transportation of goods and nacelles.

Enercon inaugurated two new production facilities for glass-reinforced plastic components and generators in Magdeburg. The rotor blade blanks produced here will be used for Enercon's E-126, E-101, and E-82 WEC series, while generators are produced for the E-101 and E-115 WEC series. According to press releases, both plants together will employ up to approximately 350 people.

Senvion, formerly a part of Suzlon Energy, changed owners. The investment management firm Centerbridge Partners, which is focusing on private equity and credit investment opportunities, has fully acquired the Hamburg-based company, which operates production facilities in Germany in Husum, Bremerhaven, and Trampe. The company, which erected its 2,000th land-based wind turbine in Germany in 2015, changed its entity status from an SE (European company) to a GmbH (German limited liability company).

### 3.3 Operational details

The trend of declining specific power densities continues. Newly installed wind turbines had an average specific power density of 326 W/$m^2$, 10% less compared to the previous year [4]. This is caused by increasing rotor diameters with only moderate growth of the rated power. Turbine manufacturers are reacting to the demand for wind turbines in moderate wind conditions with reasonable full load hours. These kinds of turbines are especially attractive for inner-land locations. Figure 3 shows the growth of the annual average land-based turbine sizes in Germany.

In conjunction with a relatively windy year in 2015, the capacity factor increased compared to the relatively weak three previous years and is now significantly above the long-term average.

As in the previous years, December turned out to be the most productive wind month of the year and surpassed the production from lignite-fired power plants for the first time ever. Annual wind energy generation (88.0 TWh) was almost tied with nuclear power plants (91.8 TWh) for third place, behind lignite-fired power plants (155.0 TWh) and stone-coal-fired power plants (118.0 TWh) [13].

Offshore wind energy was extraordinary in 2015 for Germany. Nine offshore wind farms became fully operational and grid connected. Six projects were supplied by Siemens, two by Adwen, and one by Senvion. With 400 MW, Global Tech I was the largest project of the nine new wind farms, which averaged 296 MW in size. In total, 13 offshore wind farms were operational and grid connected by the end of 2015. Four offshore wind farms were under construction in the Northern Sea and financial decisions have been made for an additional three [3].

Repowering dropped significantly from 1,148 MW in 2014 to 484 MW in 2015 [4]. This is partly caused by a change of definition. Formerly, a wind turbine was eligible for a repowering bonus if it was in the same, or neighboring, administrative district of an old wind turbine being dismantled. This changed with the amendment of the EEG. The repowering bonus was withdrawn and repowering was redefined as a wind turbine that is directly replaced by a newer wind turbine.

Several German-based manufacturers announced new turbines, blades, or testing capabilities in 2015. Enercon introduced its new model line within the 4-MW segment. The first is a new 4.2-MW model with a rotor diameter of 127 m, tailored for wind class IEC IIA. The E-126 EP4 will feature segmented rotor blades with trailing edge serrations. The Aurich-based company also announced a low wind version E-141 EP4 for wind class III, the components of which are almost identical to the E-126 EP4, except it has longer, 141-m rotor blades. While an EP4 prototype has been installed in 2015, it is expected that serial production will start in 2017.

With the N131/3300, Nordex also introduced a new turbine tailored to Germany's low wind speed regions and could successfully install a first turbine in December 2015. The 3.3-MW turbine is based on Nordex's delta platform and delivers a specific power density of 245 W/$m^2$. The company guarantees a maximum sound level of just 104.5 dB(A). The turbines will have two hybrid tower options, 134-m hub height or 164-m hub height. The former will be available mid-2016, the latter is expected to arrive at the end of 2016.

Senvion also announced a new dedicated low wind speed turbine. The 3.2M122 turbine features Senvion's so-called Next Electrical System (NES), comprising a fully rated converter and an asynchronous generator. The 3.2-MW wind turbine, with a rotor diameter of 122 m, will provide a more stable grid feed-in due to the improved properties which have been tailored to grid operator requirements. Senvion also finished commissioning and the initial test phase for the prototype of its 6.2-MW machine. This wind turbine is equipped with a 152-m diameter rotor and has been designed for a 25-year life time.

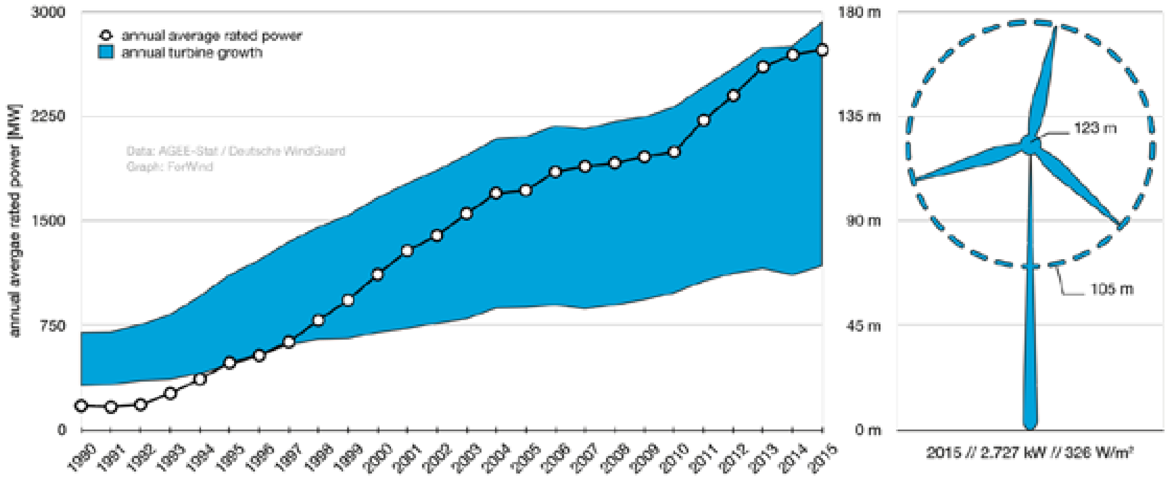

Figure 3. Growth of the annual average land-based turbine sizes in Germany 2015 [4]

Siemens introduced an updated version of its large direct drive offshore wind turbine. The SWT-7.0-154 now provides 7.0 MW of nominal power. The company installed the first prototype of a 156-m rotor diameter wind turbine at the Danish test site in Østerild and received a first order for 47 units to be installed in the Irish Sea offshore wind park Walney Extension East.

Fraunhofer IWES and Adwen signed an agreement to test Adwen's next generation 8-MW turbine at IWES's Dynamic Nacelle Testing Laboratory (DyNaLab). Mechanical testing on the integral chain of drive train components will be carried out by simulating operational conditions as well as extreme fatigue loads. That way the company will reduce risks before the planned prototype is installed in 2016.

### 3.4 Wind energy costs

Project-specific costs are hard to get and can vary significantly. For land-based wind energy, an updated picture is available from the report "Kostensituation der Windenergie an Land in Deutschland" [14]. Main investment costs, i.e., turbine, transport, and installation, are dependent on hub heights and rated power. Based on a survey, which covers six OEMs with a 97% market share, costs for wind turbines in the range of 2 to 3 MW vary between 980 EUR/kW and 1,380 EUR/kW (1,066 USD/kW and 1,501 USD/kW), while main investment costs for wind turbines in the range of 3 to 4 MW vary between 990 EUR/kW and 1,230 EUR/kW (1,077 USD/kW and 1,338 USD/kW). Generally speaking, the main investment costs for larger (rated power) turbines are below those of smaller turbines. Technical improvements and new concepts allowed for specific main investment cost to be reduced. Compared to 2012, costs dropped by 2–11%, depending on turbine types, with an average reduction in costs of 7%.

On average, the additional costs, e.g., foundation, grid connection, site development, planning, and other costs, stayed more or less stable at 387 EUR/kW (421 USD/kW). However, these additional costs can be extremely site dependent as are the operational costs. For the latter, maintenance and repair represent the largest share. Within the first ten years of operation maintenance and repair account for 44% of the operational costs and 55% of the costs in the last ten years. Lease and system management are the second and third most important factors with respect to operational costs.

Based on the fixed and variable costs, averaged actual costs of land-based wind projects which will be connected in 2016 and 2017, can be estimated to vary between 0.053 EUR/kWh (0.058 USD/kWh) for 150% sites and 0.096 EUR/kWh (0.104 USD/kWh) for 60% sites, based on a 100% site, which is estimated with 0.067 EUR/kWh (0.073 USD/kWh).

## 4.0 R, D&D Activities

### 4.1 National R, D&D efforts

For the first time, wind energy provided 87.98 billion kWh in 2015, which is 50% more electricity than in 2014 (57.4 billion kWh).

The German national R, D&D efforts within the ongoing 6th Energy Research Program supported wind energy deployment with several funding measures making wind turbines more efficient and their operation reliable to therefore lower the cost. Land-based wind energy is a central part of the German Energy Transition because it is currently the most cost-effective technology for electricity generation of all renewable energies in Germany. Furthermore, it provided the largest portion of electricity by renewables in 2015. The intensified use of offshore wind energy, as well as the strengthened exploitation of land-based sites, together has built a high potential for Germany's future wind energy development.

In 2015, 103 new research projects were initiated by the Federal Ministry for Economic Affairs and Energy with funding of 85.4 million EUR (92.92 million USD), as shown in Figure 4 [1]. In addition, seven projects received 5.7 million EUR (6.2 million USD) as updated funds. So the total amount of funding in 2015 was 99.1 million EUR (107.8 million USD) for 110 projects. In comparison, the funding in 2014 amounted to 38.51 million EUR (41.89 million USD). With 284 ongoing projects in 2015, the funding amounted to 53.04 million EUR (57.71 million USD), compared to 2014 with 53.06 million EUR (57.73 million USD); thus it remained at a stable level compared to prior years.

German research efforts are focused on larger rotor diameters, wind turbines for weak wind conditions, and especially turbines with low noise rotor blades. Also, the modularization of wind turbines (including segmented test methods of rotor blades), resource efficiency, and increased performance play an important role in keeping wind energy costs low. Another topic of interest is to make electricity generation by wind energy more predictable, especially in complex terrains. Development of simulation procedures for wind loads and new and optimized control strategies are being investigated. The following are examples of the R, D&D projects on these topics:

- The "HAPT – Highly Accelerated Pitch Bearing Test" aims to increase the reliability of rotor blade bearings and facilitate the application of new bearing-related technologies in wind turbines with a power of up to 10 MW. This is achieved through calculation models as well as test strategies. For the application of test strategies, a 1:1 scaled test rig is designed and manufactured. Four blade bearings for the 7-MW class will undergo tests on this rig in order to validate the calculation model and test strategy.
- The "BiSWind" project aims to implement a new measurement and maintenance principle for load transmission elements in highly loaded systems, such as wind turbines. An autonomously operating Condition Monitoring System is to be created, which will enable the measurement of torque, temperature, vibration and speed quasi-continuously. This sensor system requires robust thin film sensors which are coated directly on technical surfaces and a customized low-energy electronic module. In order to make the whole system independent of external energy sources, integrated power generation from motion and energy storage is required. In combination with efficient low-energy microelectronics and low-energy data transmission, autonomous operation shall be possible during the entire operating time of the wind turbine.

Another important development in 2015 is the updated regulation on identification of aviation obstacles which requires, from now on, event-based aviation navigation lights for wind turbines at night making land-based wind energy development socially more acceptable.

Several testing facilities are available in Germany. In late 2015, the Dynamic Nacelle Testing Laboratory (DyNaLab) in Bremerhaven, with a drive capacity of 10 MW and a virtual grid capacity of up to 36 kV (44 MVA inverter performance), was officially inaugurated. Within this unique testing facility, adverse conditions like lightning strikes, short-circuit faults, and storm gusts can be simulated. Pilot tests of several manufacturer's nacelles are going on.

A state-of-the-art procedure was developed for low noise installation of offshore foundations in water depths up to 40 m using big bubble curtains. Sound exposure thresholds can be met with the help of these additional measures. And since they reduce the disturbance area for marine mammals by up to 90%, species conservation is ensured within the German Exclusive Economic Zone. Low noise techniques like suction bucket jackets are also being investigated.

Further topics of interest include new concepts for offshore installation and logistics, grid integration of offshore windfarms, load management, and wind energy specific energy storage issues [1, 11].

### 4.2 Collaborative research

German scientists and experts from industry continue to participating in 13 of 15 active IEA Wind Technology Collaboration Programme (TCP) research tasks (Task 11 Base Technology Information Exchange, Task 19 Wind Energy in Cold Climates, Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power, Task 26 Cost of Wind Energy, Task 28 Social Acceptance of Wind Energy Projects, Task 29 Mexnext: Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models, Task 30 Offshore Code Comparison Collaboration Continued with Correlation (OC5) Project, Task 31 WAKEBENCH: Benchmarking of Wind Farm Flow Models, Task 32 LIDAR: Lidar Systems for Wind Energy Deployment, Task 33 Reliability Data: Standardizing Data Collection for Wind Turbine Reliability, Operation, and Maintenance Analysis, Task 35 Full-Size, Ground Testing for Wind Turbines and Their Components, as well as Task 36 Forecasting for Wind Energy and Task 37 Wind Energy Systems Engineering: Integrated R, D&D.) Five of these tasks are chaired or co-chaired by German research institutions as operating agent or work package leader.

Besides this collaborative research in the IEA Wind TCP, Germany keeps on strengthening its European networking within the implementation of the European Strategic Energy Technology (SET) Plan via research co-operations like ERA-Nets+ (European Research Area Networks) and bi- and multi-lateral research projects on the basis of the so called "Berlin model." Before multi-lateral research projects apply for European funding in the latter case, they go through a national process of applying for funding. In Germany, they must successfully complete a two-stage proposal process [11].

## 5.0 The Next Term

The most important change in 2016 is the EEG amendment. From 2017 on, new wind energy projects will no longer receive the fixed FIT. The new system will be based on tenders, with exceptions for an annual portfolio of 125 MW for prototypes, small projects (below 750 kW), and projects that received their permits in 2016. The annual goal for gross added land-based capacity is planned to be reduced to 2.8–2.9 GW [6, 17, 18].

To address Germany's future R&D strategy and key aspects on renewable energies, especially wind energy and photovoltaics, the so called "Forschungsnetzwerk Energie—Erneuerbare Energien" (Research Network for Renewable Energies) was launched by the Federal Ministry for Economic Affairs and Energy in early 2016. This purely national network, coordinated by Forschungszentrum Jülich GmbH—Project Management Jülich, gives representatives from research, industry, and politics a platform for information and discussion. It will work as an open expert forum to share information on the specific technologies and develop research roadmaps [15].

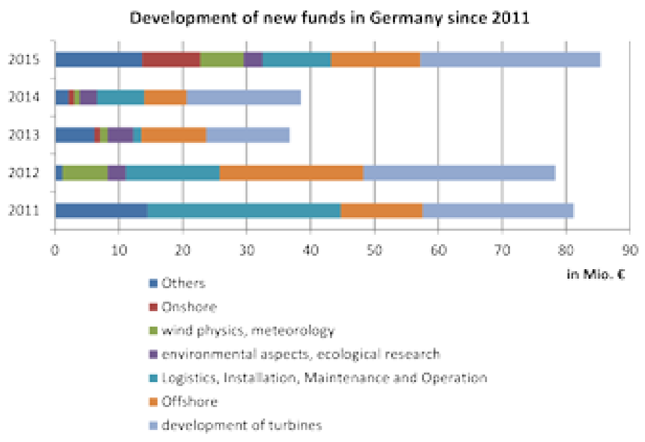

Figure 4. Development of new R, D&D funds in Germany since 2011 [1]

Future focus for research topics shall lower the costs for electricity generation by wind energy. This will be done by increasing the yields and making wind farms' operation more reliable. This includes ongoing research on components and the development of optimized control strategies for wind turbines and wind farms. Another important issue for the increased deployment of wind energy is to make electricity generation much more predictable. Therefore, the Federal Ministry for Economic Affairs and Energy continues to support its national R, D&D efforts on wind energy within the ongoing 6th Energy Research Program including collaborative research with a mutual benefit for Germany and its international partners.

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Opening photo: Vestas V90 wind turbine at Mont-Soleil, St. Imier, Suisse; see www.juvent.ch/übersicht.html. (Photo credit: Franciska Klein)

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Authors: Franciska Klein, Project Management Jülich—Forschungszentrum Jülich GmbH, and Stephan Barth, ForWind—Center for Wind Energy Research, Germany.

# 27 Greece

## 1.0 Overview

In 2015, 172 MW of new wind capacity were installed in Greece (Table 1 and Figure 1). This 8.7% increase brings the total installed wind capacity to 2,152 MW. The electrical output from wind generation in Greece totaled 3.5 TWh and wind generation as a percent of the national electric demand was approximately 7.1% [1].

At the close of 2015, a total of 176 wind farms were operating in Greece [2]. The weighted average price of wind energy was 89.4 EUR/MWh (97.3 USD/MWh) [3]. Greek wind energy will have to increase significantly in order to reach the target of 7,500 MW by 2020 set by the National Renewable Energy Action Plan.

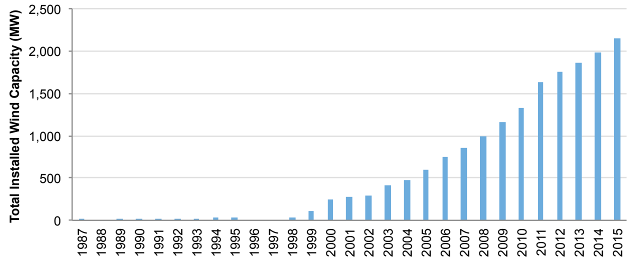

Figure 1. Total installed wind capacity in Greece 1987–2015 (Source: HWEA)

**Table 1. Key National Statistics 2015: Greece**

| | |
|---|---|
| Total (net) installed wind capacity[a] | 2,152 MW |
| New wind generation installed[a] | 172 MW |
| Total electrical output from wind[b] | 3.5 TWh |
| Wind-generated electricity as a % of national electric demand | ***7.1*** |
| Target: | 7,500 MW by 2020 |

***Bold italics*** indicate estimates
[a] Hellenic Wind Energy Association (HWEA) Wind Energy Statistics 2015
[b] ENTSO-E [1]

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Opening photo: Skopies wind farm (Courtesy: Iberdrola)

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# 28 Ireland

## 1.0 Overview

**With 244 MW of new capacity added in 2105, the rate of construction of new wind farms, while below the 2014 peak, continued above the average annual rate since 2010. The combination of continued strong growth in capacity and above average annual wind speeds resulted in the wind energy contribution to electricity demand in 2015 increasing to 22.8%, which is an increase of over 25% since 2014. Wind energy provided the dominant share of the 25% total renewable energy contribution to electricity demand. The average annual aggregate national wind plant capacity factor was 32.3%.**

**The current Renewable Energy Feed-in Tariff (REFIT 2) renewable electricity support scheme closed to new applications at the end of 2015 [1]. Wind farm developers continue to execute qualifying permitted projects in time to meet support scheme deadline of the end of 2017. The government consultation on a replacement renewable electricity support scheme was published in July 2015 [2]. The government also published an energy policy white paper in December 2015 setting the context for energy policy for the period up to 2030 [3].**

**Wind farm project economics remained favorable in Ireland in 2015 due to stable low wind turbine prices and declining interest rates, although some other project cost elements inflated.**

**The proposed implementation of the Integrated Single Energy Market (ISEM)—modified electricity market arrangements to conform to the EU Target Market Model—was finalized in 2015 [4]. The arrangements include an aggregator of last resort to facilitate small independent wind power plant participation in the market.**

**The permitting environment for wind farms continued to become more challenging in 2015. Judicial reviews were sought for a majority of the planning appeals board's decisions that favored wind farm developments and some were subsequently overturned. The publication of revised planning guidance for wind farms was postponed.**

## 2.0 National Objectives and Progress

### 2.1 National targets

Ireland is committed to an EU target of meeting 16% of its total energy demand from renewable energy by 2020. The greatest share of this target will be met in the electricity sector with an indicative target of 40% of electricity demand to be met from renewable sources. An assessment of projected contributions to this renewable electricity target indicates that 32% of electricity demand, or 80% of the renewable electricity target, will be met from land-based wind energy and that wind energy will contribute approximately 7% out of the overall 16% national renewable energy target.

A generation capacity review in early 2016 identified that 3,800–4,100 MW of additional wind power will now be required in 2020 to meet the 40% renewable electricity target as set out in the National Renewable Energy Action Plan (NREAP) due to a projected increase in electricity demand [5, 6]. This will now involve around 1,500 MW of new wind power capacity being added over the next five years.

### 2.2 Progress

The installed and energized wind capacity at the end of 2015 was 2,455 MW (Figure 1). The 244 MW added during 2015 is less than the all-time peak of 270 MW in 2014. With recent revised electricity demand projections for 2020, the deployment rate is now below the trajectory to achieve the wind energy contribution to Ireland's 2020 renewable energy targets.

The 6.6 TWh output from wind energy was an increase of 25% over 2014 and accounted for 22.8% of the electricity demand in 2015, making it the second most significant source of electricity after natural gas at 45.8%. While wind energy contributes to reducing the carbon intensity of electricity generation, provisional figures indicate an increase of 2.3% in overall emissions intensity to 467 g $CO_2$/kWh in 2015 due to an increased use of coal and peat fired generation in place of gas.

### 2.3 National incentive programs

The primary support scheme for renewable electricity in Ireland is the REFIT scheme [1]. This scheme has been in place since 2006 and the arrangements have been detailed in previous IEA Wind Annual Reports. Projects qualifying for the REFIT 1 scheme had an execution deadline of the end of 2015. The replacement REFIT 2 scheme opened in March 2012 with deadlines of December 2015, for applications, and of the end of 2017 for the energization of qualifying projects. The tariff levels defined under REFIT 1 and REFIT 2 are identical but the arrangements for market compensation accruing to power purchase agreement counterparties are modified under REFIT 2. The REFIT schemes did not include an FIT for offshore wind or small wind turbines.

The cost of the REFIT support scheme is recovered through a levy on all electricity consumers. The projected cost of this levy for wind power in 2014/15 was approximately 90 million EUR (98 million USD) [7]. This cost projection does not consider the compensating depression of electricity prices by wind power. The inflation adjusted REFIT tariffs for wind in 2015 were 69.72 EUR/MWh (75.86 USD/MWh) for wind farms larger than 5 MW and 72.167 EUR/MWh (78.518 USD/MWh) for wind farms smaller than 5 MW [1].

Given the imminent closure of the REFIT 2 scheme, the government published an initial consultation on a future replacement renewable electricity support scheme in July 2015 [2]. This will be followed by publication of the high level scheme design for consultation and a final detailed design in 2016. The scheme design will give consideration to EU state aid rules affecting support schemes.

### 2.4 Issues affecting growth

The 241 MW wind energy capacity added in 2015, while below that achieved in 2014, is above the average annual addition since 2010. The rate of provision of "firm" wind farm grid connections has largely determined the rate of deployment of wind energy in Ireland.

Toward the end of 2015 the Commission for Energy Regulation issued a consultation on a review of the generator connection process, possibly stimulated by a surge in connection applications for solar PV farms [9]. The consultation document reported that "Recent figures provided by the SO's indicate that there is currently 2,380 MW of installed wind capacity, and 3,510 MW of contracted wind capacity." This indicates that there are sufficient wind farm connection agreements to meet 2020 targets and continue to contribute to, as yet unidentified, 2030 policy objectives.

Curtailment of wind output had risen throughout 2014 with total dispatch down of wind energy reaching 4.4% [10]. Curtailment continued to rise with the growth in wind output during 2015 until October, when the system operator, Eirgrid, implemented a planned increase of the system limit on instantaneous wind energy penetration from 50% to 55%. The reports on dispatch down levels for this period are as yet unavailable, but this measure should result in a significant reduction in wind curtailment.

Favorable wind turbine prices and low interest rates provide the industry with good economic underpinnings and there is a strong appetite to build out consented projects.

The primary challenges to sustaining the rate of capacity addition are as follows:

- The closure of the current REFIT support mechanism for applications with the details of a replacement scheme yet to be announced;
- The replacement of the current Single Energy Market (SEM) mandatory gross pool market with new ISEM electricity market arrangements include a balancing market that may disadvantage small wind farms [4];
- Some proposed measures to reduce curtailment for future very high penetrations of wind are behind schedule in their implementation [11];
- Increased community and political disquiet about wind farm developments;
- Increasing numbers of judicial reviews of the planning appeals board's decisions in favor of wind farm planning applications and uncertainty regarding the implementation in regulations of some resulting court decisions;

**Table 1. Key National Statistics 2015: Ireland**

| | |
|---|---|
| Total (net) installed wind capacity | 2,455 MW |
| New wind capacity installed | 244 MW |
| Total electrical output from wind | 6.6 TWh |
| Wind-generated electricity as a % of national electric demand | 22.8% |
| Average national capacity factor | ***32.3%*** |
| Target: | 40% RES-E in 2020 |
| ***Bold italic*** indicates estimates | |

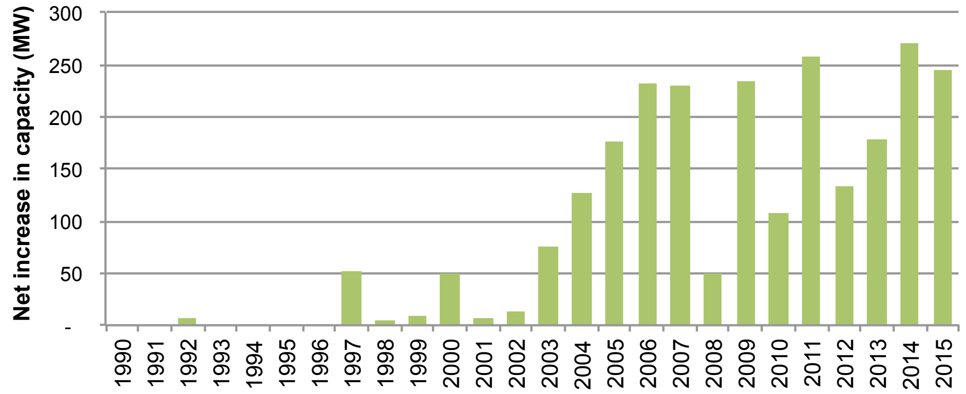

Figure 1. Annual wind farm capacity additions 1992–2015

- The 2013 draft revised wind farm planning guidance concerning noise and shadow flicker has yet to be finalized.

## 3.0 Implementation

### 3.1 Economic impact

In 2015 the Sustainable Energy Authority of Ireland (SEAI) published a report titled *A Macroeconomic Analysis of Onshore Wind Deployment to 2020* summarizing the results of detailed analysis which showed that, in addition to reducing reliance on imported fossil fuels and reducing greenhouse gas emissions, reaching Ireland's 2020 renewable energy targets for heat (12% RES-H) and electricity (40% RES-E) will also deliver positive macroeconomic and net employment benefits [12]. The results of the analysis presented the net new direct jobs (from new technology installations), indirect jobs (created in supply chains), induced jobs (from increased consumption), and jobs linked to increased investment in capital stock in the year 2020. These employment gains flow from anticipated investment over the period 2013–2020, while also taking into account changes in prices, incomes, and output in the wider economy.

Anticipated wind deployment, sufficient to reach the 40% renewable electricity target in Ireland by 2020, would have a positive impact on the Irish economy and net employment.

- Between 2,880 and 6,000 net jobs could be created in 2020. The extent of the increase depends on how wind deployment impacts on future electricity prices.
- Around 2,000 of the new jobs are anticipated to be created directly in the construction sector. The extent to which these levels of new jobs persist post-2020 will depend on future deployment and repowering of existing sites. Around 500 ongoing direct jobs in operations and maintenance of existing turbines would be created.
- Employment benefits are maximized in the case that savings accrue to consumers due to increased wind deployment. Any savings lead to increased indirect employment in sectors supporting wind deployment and from induced employment created by increased expenditure in the economy.
- In the event of a future electricity price rise due to increased wind deployment, fewer indirect jobs and induced jobs are created in the economy—however, the total economy wide employment impacts remain positive.
- The employment impacts stem from the anticipated total capital investment of approximately 270 million EUR (294 million USD) in 2020 in wind turbines, plus the associated investment in the transmission grid to facilitate renewable sources of electricity.

In terms of wider macroeconomic impacts in 2020, GDP could increase by 305–585 million EUR (332–637 million USD) (2012 prices). The additional employment drives increases in average income per capita and real disposable income in 2020 (where electricity cost savings are made).

### 3.2 Industry status

The profile and market share of the main wind farm developer categories in Ireland was detailed in the *IEA Wind 2014 Annual Report*. Further key characteristics of the wind energy sector are detailed below.

#### 3.2.1 Wind turbine manufacturer market share

Enercon and Vestas have the dominant market shares with over 50% of the market in roughly equal shares between them. GE Wind, Nordex, and Siemens come next sharing one third of the market of the market with Gamesa following with a smaller 3% market share.

Figure 2 shows the evolution of the market share of the manufacturers on a year by year basis. While Vestas had a dominant market share up until 2006, after this Enercon, GE Wind, Nordex, and Siemens made significant gains in market share. These latter companies have dominated the market since 2007 and their individual annual market shares fluctuate from year to year heavily influenced by the number of large wind farm projects, if any, falling within a particular year. The Irish wind turbine supply sector could therefore be characterised as having evolved to a state of robust competition with no single manufacturer having a dominant share.

The market might be further characterised by contrasting the period from 1992 to 2006 with the period from 2007 to 2015 illustrated in Figure 3. Prior to 2006, Vestas dominated the market with an almost 50% market share.

From 2007 onward, the Vestas market share declined and Enercon became the leading turbine provider in the Irish market. More detailed examination of the underlying data reveals that Enercon is particularly active in supplying wind turbines for the great number of small projects that are a characteristic of the Irish wind energy sector. The other manufacturers share the larger projects.

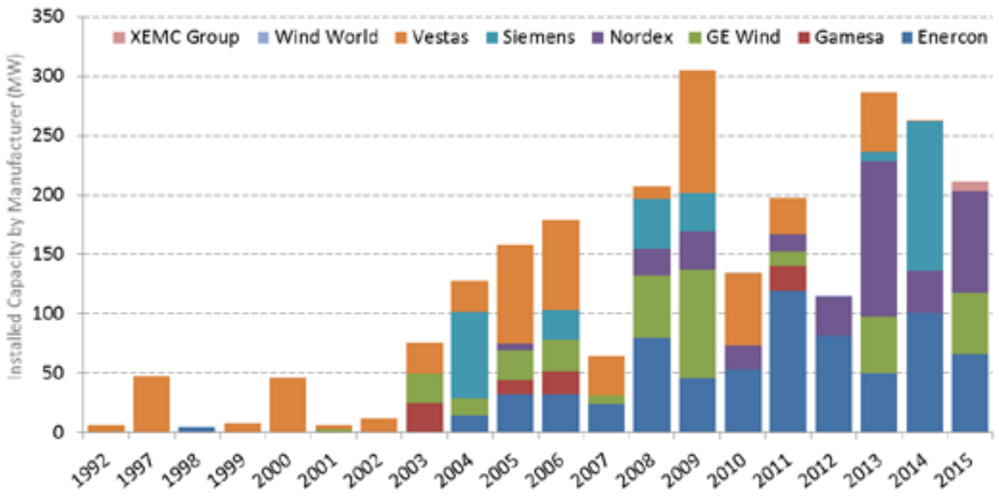

Figure 2. Wind turbine manufacturer annual market share (1992–2015)

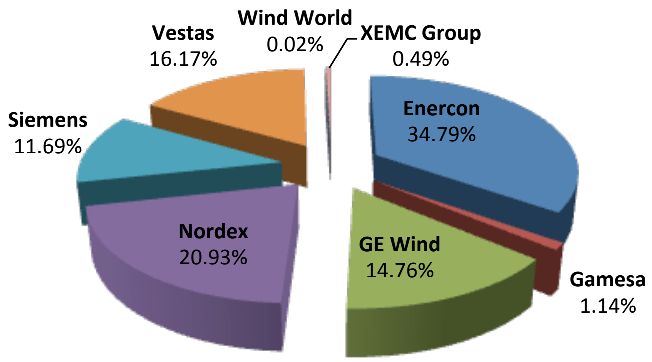

Figure 3. Wind turbine manufacturer total market share (2007–2015)

Figure 4 illustrates the historical trend in installed wind turbine hub height based upon numbers of turbines installed. There has been a long term gradual upward trend in the annual average hub height and rotor diameter, this is primarily influenced by international trends towards larger wind turbines and the associated improved project economics. While the early wind farm sites typically benefited from favourable wind speeds at lower hub heights, exploitation of the wind resource more extensively required taller towers in order to maintain viable hub height wind speeds.

Figure 5 provides more detail of the trends in wind turbine tower height. The top and bottom of each rectangle delimit the 25th and 75th percentile range. The horizontal line inside each rectangle represents the median and the lower and upper horizontal lines outside the rectangles are the minimum and maximum values. A jump in hub heights in 2014 due to the coincidence of a number of large projects with taller towers was not sustained into 2015.

The graph exhibits a very wide range and incudes some individual autoproduction wind turbines which may typically represent the lower limit of the range. The size range 75th percentile band may be more representative of typical supply.

Larger turbines make a proportionately greater per-turbine contribution to energy supply and charts based upon wind turbine count may not adequately represent this.

Figure 6 illustrates the evolution of wind turbine size trends and the influence of these upon the numbers of turbines required to deliver increasing annual installed capacities. There has been a decline in the use of sub 1-MW wind turbines in recent years. It is also noticeable that, since 2006, the annual installed capacity is not strongly linked to the number of turbines installed. The use of larger turbines has facilitated greater annual capacity additions with fewer turbines with an associated impact upon the total numbers of turbines required to achieve national renewable energy targets.

#### 3.2.2 Wind farm project size

Figure 7 shows the trend in average wind farm project size which has increased to around 20 MW in recent years.

Figure 8 shows the historical trend of the number of wind farm projects falling within a range of size categories over successive five-year intervals. This exhibits some distinctive characteristics. While the current average size of a wind farm project is now around 20 MW, projects of this size represent a relative minority of the total project cohort. In the early years, the majority of projects were less than 5 MW. After 2005 projects in the 5–10 MW size range increased dramatically in number but declined somewhat post 2010. Greater numbers of projects larger than 30 MW have been a consistent feature since 2005. Figure 8 shows the capacity contributions from projects in the same size ranges and illustrates the emerging important contribution of a relatively small number of large projects.

### 3.3 Operational details

The largest new wind farm in 2015 was SSE Airtricity's 65-MW Boggeragh wind farm, in Co. Cork, comprising of 26 Nordex N90 2.5-MW turbines. XEMC wind turbines were used for the first time on Irish wind farms in 2015, with 2-MW turbines being used on Gaelectric's Roosky project and 2.4-MW turbines on their Leabeg wind farm.

The average annual aggregate wind plant capacity factor in 2015 was 32.3%, which was above the long-term mean of 30.8%. A windy summer and stormy winter led to above average production throughout the year. Figure 10 shows the historic trend of annual capacity factors.

# 28 Ireland

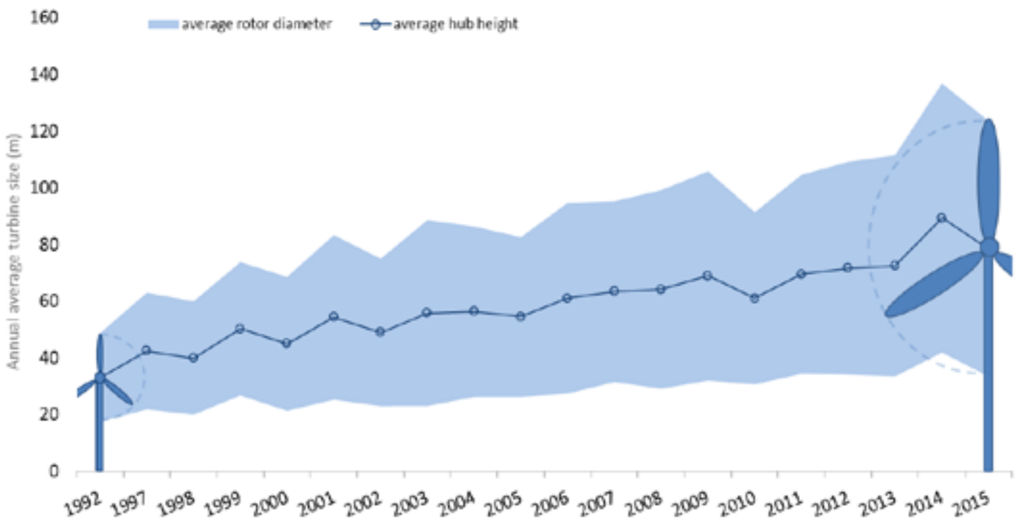

Figure 4. Wind turbine average hub height and rotor diameter (1992–2015)

**3.4 Wind energy costs**

Wind turbine prices in 2015 continued to favor buyers and averaged 850 EUR/kW (925 USD/kW) for medium to large projects and 950 EUR/kW (1,034 USD/kW) for small projects less than 10 MW. Total wind farm capital expenditure costs averaged 1,600 EUR/kW (1,741 USD/kW) for larger projects in 2015 and 1,700 EUR/MW (1,850 USD/MW) for projects smaller than 10 MW, the small increase on 2014 costs primarily due to increasing grid connection costs.

The above costs do not include legal and financing fees which might add 150 EUR/kW (163 USD/kW) for large projects and 200 EUR/kW (218 USD/kW) for smaller projects. The effects of rising costs were somewhat offset by low interest rates, which served to sustain an attractive rate of return for wind farm investors.

## 4.0 R, D&D Activities

### 4.1 National R, D&D efforts

The main bodies funding state sponsored wind energy R, D&D in Ireland are as follows:

- SEAI, which carries out energy policy research and implements R, D&D programs on behalf of the Department of Communications, Energy, and Natura Resources (DCENR) supporting renewable energy deployment;
- The Science Foundation Ireland/Irish Research Council funds basic academic research on science and technology. The priorities are guided by the 2013 report of the Research Prioritisation Steering Group which recommended 14 areas of opportunity as well as underpinning technologies and infrastructure to support these priority areas. These areas should receive the majority of competitive public investment in science, technology and innovation over a five year period ending 2017 [13]. The 14 identified national priorities included two energy priorities, Marine Renewable Energy and Smart Grids and Smart Cities. Wind energy was not identified as a research priority even though it will make the largest contribution to Ireland's 2020 renewable energy target;
- Enterprise Ireland funds research commercialization within indigenous Small and Medium-sized Enterprises (SMEs). Wind energy projects it has funded include small wind turbine development and data systems for wind farm O&M.

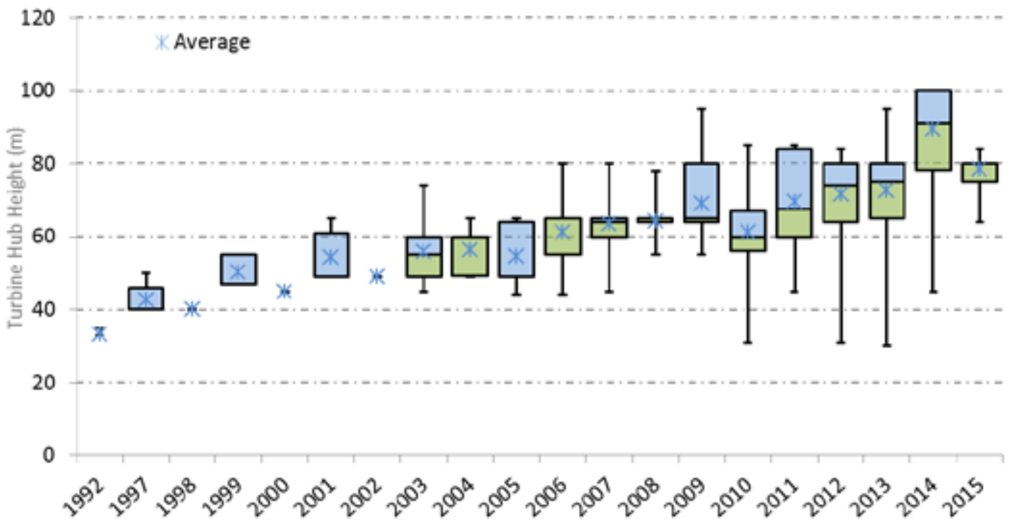

Figure 5. Wind turbine hub height (1992–2015)

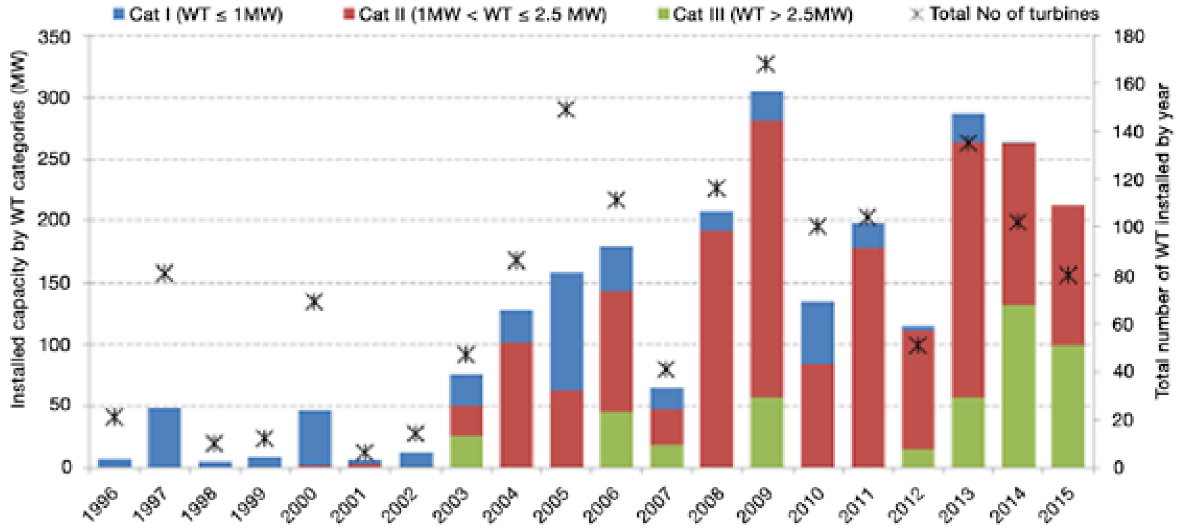

Figure 6. Wind turbine capacity additions by size band (1992–2015)

Also:

- Eirgrid, the all-island Transmission System Operator (TSO), carries out and funds research on the electricity system integration of wind energy and has also established the Smart Grid Innovation Hub within the National Digital Research Centre. The goal is to promote the development of innovative Smart Grid solutions, with a focus on entrepreneurial initiatives by companies, academics, and entrepreneurs;
- ESB Networks, the Irish Distribution Network Operator, has sponsored research on distribution network development for high renewable electricity penetrations. Projects have included research on maximizing the levels of distribution connected wind and the EU Horizon 2020 funded Smart Green Circuits project;
- The Commission for Energy Regulation has an energy research remit within its regulatory functions and has commissioned research on the market considerations for increasing wind energy penetration in the electricity system.

Wind energy related R, D&D projects that SEAI funded in 2015 are as follows:

- Trinity College Dublin—Small/Medium Wind (Online) Platform
- NovoGrid—Wind Farm Electrical Network Efficiency Improvement
- R&R Mechanical—Grid Connected Hybrid Battery Flywheel System
- Queens University Belfast—Media Monitoring to Assess Public Response to Wind

SEAI continued to commission research work supporting the implementation of draft revised Wind Farm Planning Guidelines in 2015, in particular modeling the effects of a range of potential noise limits.

#### 4.1.1 SEES wind energy related research projects

The Sustainable Electrical Energy Systems Strategic Research Cluster (SEES Cluster) was formed in late 2010 to bring together the necessary multi-disciplinary expertise in electrical, mechanical and electronic engineering, applied mathematics, economics, and geology to tackle fundamental applied research and demonstration challenges to underpin the emergence of future integrated, smart, and sustainable electrical energy systems [14].

The SEES Cluster, with the financial support of Science Foundation Ireland and the Electricity Research Center industry members,

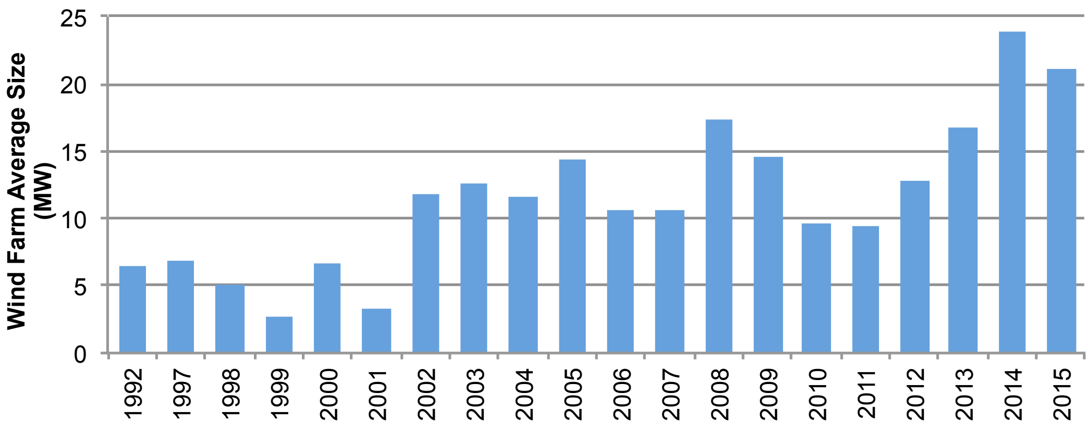

Figure 7. Wind farm average size by year

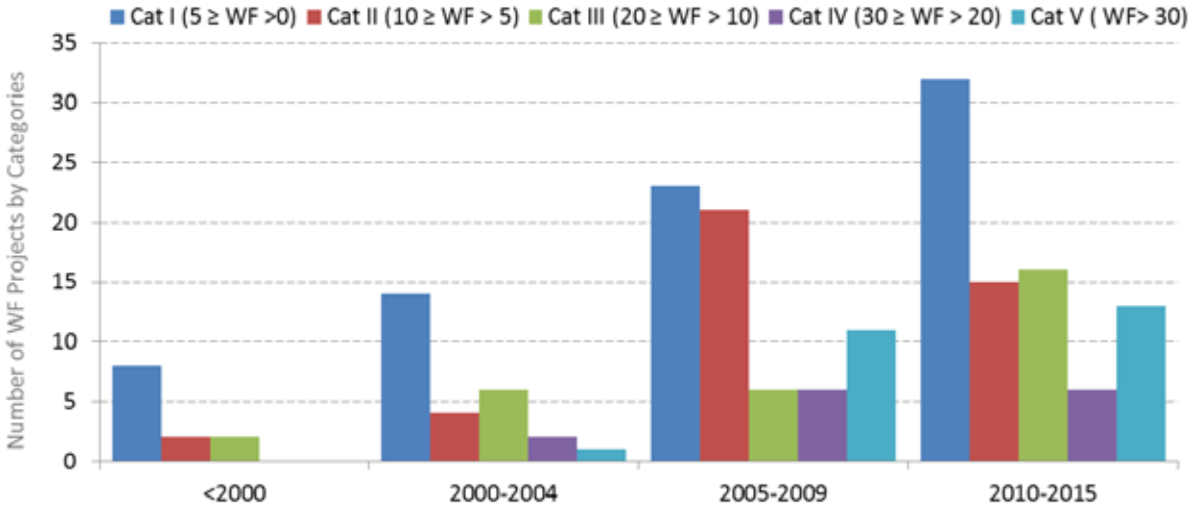

Figure 8. Number of projects by wind farm size category (1992–2015)

involves researchers in six research institutes: University College Dublin (UCD), Trinity College Dublin (TCD), University of Limerick (UL), National University of Ireland Maynooth (NUIM), and the Economic and Social Research Institute (ESRI). The Cluster has also attracted further industry interest and support.

The challenges addressed include the integration and optimization of very high, variable renewable penetrations (40% energy and above). Projects with a particular relevance to wind energy under execution during 2015 are provided here: http://erc.ucd.ie/projects/sees-cluster.

4.1.2 Eirgrid

The Eirgrid "Delivering a Secure Sustainable Electricity System" (DS3) R, D&D project is central to the delivery of Ireland's renewable electricity targets [15]. Work completed to date includes:

- Installation of the Wind Security Assessment Tool (WSAT);
- Grid code modifications to facilitate moving to 75% instantaneous asynchronous generation penetration;
- Performance monitoring and testing of all generators for meeting grid code requirements; and
- Definition of expanded system services to facilitate the future high asynchronous penetration.

Several technology demonstration projects have been funded by Eirgrid at the Smart Grid Innovation Hub within the National Digital Research Centre.

**4.2 Collaborative research**

Ireland is very active within IEA Wind and participates in seven R, D&D tasks: Task 11 Base Technology Information Exchange, Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power, Task 26 Cost of Wind Energy, Task 27 Small Wind Turbines in Highly Turbulent Sites, Task 28 Social Acceptance of Wind Energy Projects, Task 33 Reliability Data: Standardizing Data Collection for Wind Turbine Reliability, Operation, and Maintenance Analyses, and Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN).

SEAI places IEA Wind participation at the heart of its national wind energy R, D&D program, utilizing the international collaboration to establish international best practices and stimulate national research projects in areas facilitating local deployment—initiating the formation of new tasks in areas where Ireland has research leadership or which present particular barriers to wind energy in Ireland. Participation in IEA Wind has proven to be a very effective manner in which to bring research effort to bear to effectively facilitate the growth of the wind energy sector in Ireland.

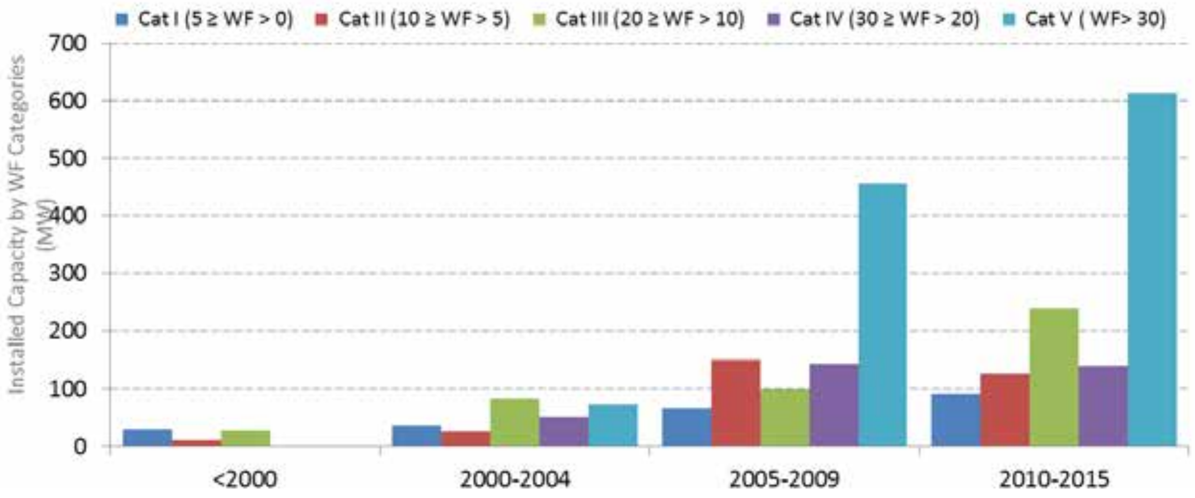

Figure 9. Installed capacity by wind farm size category (1992–2015)

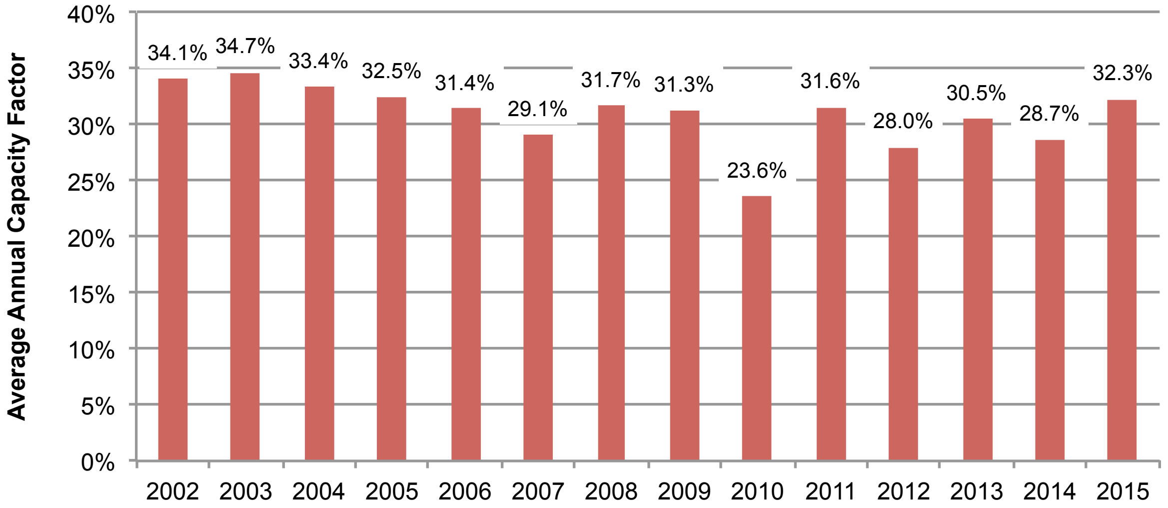

Figure 10. Annual capacity factors

## 5.0 The Next Term

After undertaking an intensive national and regional public consultation process, the Irish government published new energy policy White Paper in 2015 titled *Ireland's Transition to a Low Carbon Energy Future 2015-2030* outlining the high-level energy policy direction for the period up to 2030 [3]. The foreword to the White Paper notes that "Onshore wind will continue to make a significant contribution. But the next phase of our energy transition will see the deployment of additional technologies as solar, offshore wind and ocean technologies mature and become more cost-effective." The White Paper also incorporated an Energy Research Strategy Group (ERSG) high-level roadmap of the main research areas of focus to 2050 which included wind energy under the heading of "secure, cost effective, clean and competitive supply."

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Opening photo: Biomass harvesting with Knockaneden Wind Farm in the background, near Caherciveen, Co. Kerry (Photo credit: John Mc Cann)

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## 1.0 Overview

In 2015, new installed wind capacity in Italy was 295 MW, which represents an increase from the 105 MW installed in 2014, but a considerable decrease compared to the yearly installations from 2008 to 2012 (more than 1,000 MW/yr). Wind energy deployment in Italy has slowed significantly during the last three years. Cumulative installed capacity at the end of 2015 reached 8,942 MW.

The significant reduction of new capacity is mainly due to support scheme for renewable energy sources (RES), which came into force at the end of 2012. This scheme considers three different incentive access mechanisms: direct access, access by registration, and access by auction. Registration and auction access are constrained by established annual quotas. According to investors, the critical aspects of this scheme are: the too-low annual established quotas with respect to the annual new added capacity usually installed before 2013, the low basic tariff of the incentive, and the auction access threshold of 5 MW as plant capacity (also considered to be too low).

In 2015, 136 new turbines were deployed, reaching a total of 6,484 installed wind turbines. Wind electricity generation decreased from 15.1 TWh in 2014 to 14.6 TWh in 2015. This represents about 4.6% of total electricity demand on the Italian system (increasing from 310.5 TWh in 2014 to 315.2 TWh in 2015). In 2015, a considerable number of small wind turbines (under 200 kW) were installed in Italy. A cumulative installed capacity of approximately 50 MW and 2,000 small wind turbines were estimated at the end of 2015.

As in previous years, most of the turbines installed in 2015 were supplied by foreign producers because few Italian industries engage in large wind turbine manufacturing. However, in the small wind energy systems market, there is a strong presence of small and medium Italian industries; this market is supported by a high incentive level.

Wind energy R, D&D activities have been carried out by different entities, mainly the National Research Council (CNR), the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), the first and second national research institutions respectively, as well as Ricerca sul Sistema Energetico (RSE), some universities, and other companies. The coordination of these activities suffers from lack of a national program on wind energy. Moreover, the public funds for R&D in the wind sector have decreased in respect to previous years.

## 2.0 National Objectives and Progress

### 2.1 National targets

In 2009, Italy accepted a binding national target equaling 17% of overall annual energy consumption from RES as part of the EU renewable target of 20% of primary energy, electricity, heat, and transport. The Italian National Action Plan (PAN) for Renewable Energy, issued in June 2010, shared this overall national target among sector-based targets. A target of 26.39% RES was established for the electrical sector, corresponding about to 43.8 GW of RES on-line capacity and 98.9 TWh/yr production from RES to be reached by 2020. Wind, biomass, and solar were the main energy sources designated to hit this target. As far as 2020 wind energy targets are concerned, 12,680 MW (12,000 MW land-based and 680 MW offshore) was set as the installed capacity target and 20 TWh/yr (18 TWh/yr land-based and 2 TWh/yr offshore) as the energy production target.

### 2.2 Progress

In 2015, a new net wind capacity of 295.37 MW was installed according to National Wind Energy Association (ANEV). Cumulative installed capacity at the end of 2015 reached 8,942 MW. The corresponding growth rate was 3.3%, which is higher than in 2014 (1.2%) but lower than in 2013 (5.3%). However the 2015 value is still quite far from those registered before 2012, see Figure 1. This is mainly due to the changes in the incentive mechanism approved in 2012 (see section 2.3).

In 2015, a considerable numbers of small wind turbines (under 200 kW) were installed in Italy. A cumulative installed capacity of approximately 50 MW and 2,000 installed small wind turbines were estimated at the end of 2015.

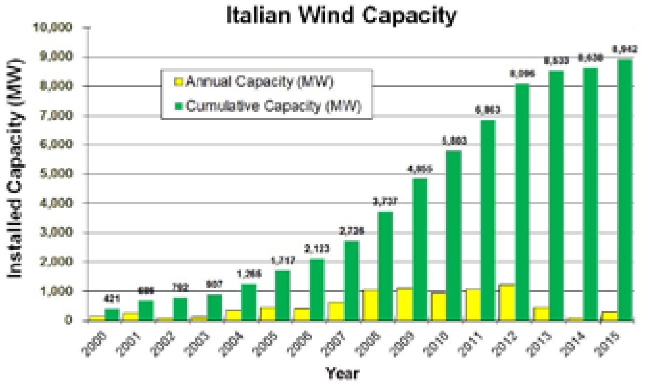

Figure 1. Trend of Italian annual and cumulative installed wind capacity (2000-2015)

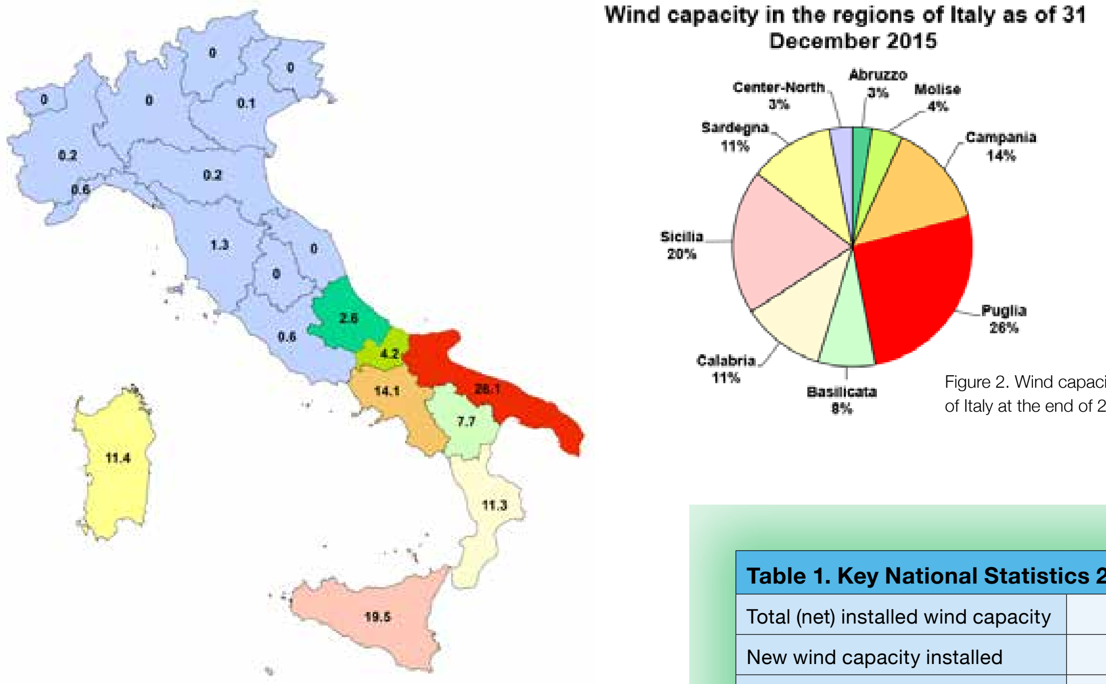

Figure 2. Wind capacities in the regions of Italy at the end of 2015

Almost all of the 2015 wind installations (247 MW) took place in Basilicata region. According to the Italian wind resource availability, most of the cumulative installations are in the southern regions of Italy, as shown in Figure 2.

In Italy, 2015 wind energy production was 14.6 TWh (estimated by TERNA provisional data) and represents 4.6% of total electricity demand on the Italian system (total consumption plus grid losses). Italian wind-energy production development is shown in Figure 3.

| Table 1. Key National Statistics 2015: Italy | |
|---|---|
| Total (net) installed wind capacity | 8,942 MW |
| New wind capacity installed | 295.4 MW |
| Total electrical output from wind | 14.6 TWh |
| Wind-generated electricity as a % of national electric demand | 4.63% |
| Average national capacity factor | 19.2% |
| Target: | 12 GW land-based and 0.68 GW offshore by 2020 |

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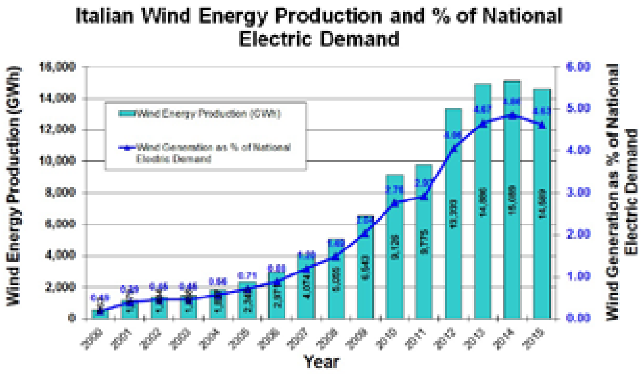


Figure 3. Trend of the annual wind energy production and percentage of wind generation on national electric demand in Italy (2000–2015)

### 2.3 National incentive programs

The incentive mechanism for RES was introduced and implemented as a consequence of the government Legislative Decree No. 28 on 3 March 2011, which recognized the EU Directive 2009/28/EC on RES promotion. The main mechanisms are special energy purchase prices fixed for RES-E plants below a capacity threshold depending on technology and size (no lower than 5 MW). Special energy purchase prices are assigned to larger plants through calls for tenders (lower bids gain contracts) and prices are granted over the average conventional lifetime of plants (20–25 years).

Concerning wind plants, three different access schemes are provided depending on plant size: direct access for plants with size lower than 60 MW, access by registration for plants with size greater than 60 MW and lower than 5 MW, and access by auction for plants with size lower than 5 MW. The 2015 annual quota established for registration access was 150 MW, for auction was 500 MW, and a surplus of 150 MW for rebuilt and repowered plants.

An overall three year (2013–2015) quota of 650 MW was established for offshore wind plant auction access.

Plants with a capacity up to 1 MW can choose between two different incentive typologies: a feed-in tariff and a tariff equal to the difference between a basic incentive tariff (plus additional rewards related to specific conditions) and the local hourly cost of electricity.

For plants with a capacity exceeding 1 MW, as the produced energy remains the producer's property, the total revenue is represented by the sum of the incentive plus the energy sale price. Conventional plant life is set at 20–25 years for land-based and offshore plants. In Table 2 the basic incentive tariff set for the period 2013–2015 are shown.

**Table 2. Conventional plant life and basic incentive tariff versus plant type and size**

| Plant Type | Plant Size (kW) | Conventional Plant Life Years (in years) | 2015 Basic Incentive Tariffs (EUR; USD) |
|---|---|---|---|
| Land-based | 1<P≤20 | 20 | 291; 317 |
| | 20<P≤200 | | 268; 292 |
| | 200<P≤1000 | | 149; 162 |
| | 1000<P≤5000 | | 135; 147 |
| | P>5000 | | 127; 138 |
| Offshore | 1000<P≤5000 | 25 | 176; 191 |
| | P>5000 | | 165; 180 |

It has to be noted that small (P<200 kW) and offshore plants still benefit from greater incentives than the land-based ones (P>200kW). Due to these more favorable incentives, small plants are growing quickly in Italy.

### 2.4 Issues affecting growth

The strong reduction in new wind capacity in 2013–2015 with respect to the previous three years (see Figure 1) is only partially due to the introduction of an annual quota. The added capacity in 2014 (105 MW) and in 2015 (295 MW) was very far from the annual quota of 500 MW actually set by GSE. The reduction is mainly due to the low level of the basic incentive tariff and to the very steep downward trend.

It has to be noted that the decree that will define incentive access procedure, quotas and tariffs after 31 December 2015 was not yet approved at the end of 2015. This fact dramatically increases the uncertainty of incentive mechanism after 2015, and questions the development of the entire wind energy sector in Italy in 2016.

If 2015 growth is constant in the next years, the 2020 national target of 12,000 MW installed land-based wind capacity will not not be achieved. An adjustment in the incentive mechanism is expected by the operators in the next few years. This adjustment would be made to match both the land-based and offshore targets. However, further reduction in basic tariffs is under consideration due to the spending review undertaken by the Italian government.

Concerning large land-based plants, other issues affecting growth are more or less the same as previous years. After the publication of the National Guidelines for wind farm installation in 2010, the regions that give the authorization for land-based wind plants set several more restrictive rules. Other issues include the widespread tourism and the complex and mountainous terrain of Italy. The population density is high and there are still some oppositions to new wind installations.

For small wind plants, the authorization process is simplified, but the landscape impact can be greater and less controlled for many isolated single wind turbines. Moreover, the impact on the electrical grid can be greater because small operators and plants cannot generally guarantee quality and safety as the larger ones do.

Concerning offshore wind plants, in 2015 (as in 2014) the absence of applications in offshore wind auction must be highlighted. There are few offshore wind projects reported in the Environmental Impact Assessment (EIA) website of the Ministry of the Environment and Protection of Land and Sea of Italy. This confirms that the interest of developers in offshore wind is decreasing.

The authorization for offshore wind plants in Italy is given by the central government (for land-based wind plants the authorization is given by regional government) after very long and complex procedures. These long and complex procedures, together with the lack of clear policies in the sector, are perceived by the operators as the main issues that are delaying the offshore wind sector development. In the past two years, several offshore park projects have been definitively rejected by the government.

Opposition to these initiatives has been shown from both regional and local administrations as well as from some environmental associations. Italian coasts are characterized by deep waters, and because of current technology, offshore wind turbines would be installed in shallow waters near the coast. The visual impact can affect the acceptance of this kind of plant, especially due to the high volume of tourism in the coastal villages and cities. Alternatively, future floating offshore wind turbines have a huge potential.

Another issue affecting growth is related to connection of wind farms to the grid, although it's less important than in the past. Italy's 2010 PAN for Renewable Energy required TERNA to plan for upgrading of the grid, which is needed to guarantee full access of RES electricity. For the period 2013–2022, TERNA planned an investment of 7.9 billion EUR (8.6 billion USD) for grid reinforcements and started to build them. Despite that, delays in grid connection, especially in the permitting of new electrical lines by local authorities, are still reported.

In the past, TERNA was compelled to ask wind farms to stop or reduce output, because of overloads or planned work in grid zones that were not yet fully adequate. In 2015, curtailments totaled 128 GWh, lower than 1% of the total wind energy production.

## 3.0 Implementation

### 3.1 Economic impact

In 2015 the economic impact of wind energy in Italy can be estimated to be about 3.0 billion EUR (3.3 billion USD). This value represents the overall contribution of three different business areas: new installations, operation and maintenance (O&M) of the online plants, and energy production and commercialization. An estimate of the contribution of new installations, including both preliminary (design, development) and executive (construction, equipping, grid-connection) activities, was about 443 million EUR (482 million USD). O&M of the online plants contributed about 292 million EUR (318 million USD). Finally, wind energy production and commercialization had an impact valued at 2.334 million EUR (2.540 million USD).

The previous trend of increased employment has reversed in the last three years, as a consequence of the dramatic investment reduction due to the new incentive system. According to ANEV, during 2015 another reduction of jobs in the wind energy sector of about 4,000 units occurred, which means about 26,000 people were employed at the end of 2015 (including direct and indirect involvement).

### 3.2 Industry status

Foreign manufacturers prevail in the Italian large-sized wind turbine market. This is clear from Figure 4, where the overall market shares of wind turbine manufacturers in Italy at the end of 2015 are shown.

The shares of the new 2015 wind capacity are: 65% by Vestas (Denmark), 15% by Gamesa (Spain), 10% by Nordex (Germany), 9% by Senvion (Germany) and 1% by Enercon (Germany). Senvion is growing rapidly in the Italian market. As for the large-sized wind turbine sector, Leitwind is the only Italian manufacturer. This company, with headquarter in Vipiteno, produces turbines in the range of 1–3 MW in factories located in Telfs (Austria) and Chennai (India).

Vestas operates in Italy through its corporate Vestas Italy, which has two production facilities, an operations office, and a customer service center in Taranto as well as offices in Rome. All the other large wind-turbine foreign manufacturers operate in Italy by their commercial offices. Italian firms have a significant share of the large wind-turbine component market, mainly for pitch and yaw system components, electrical and electronic equipment, bearings, flanges, towers, cast and forged components (hubs, shaft supports), as well as for machine tools.

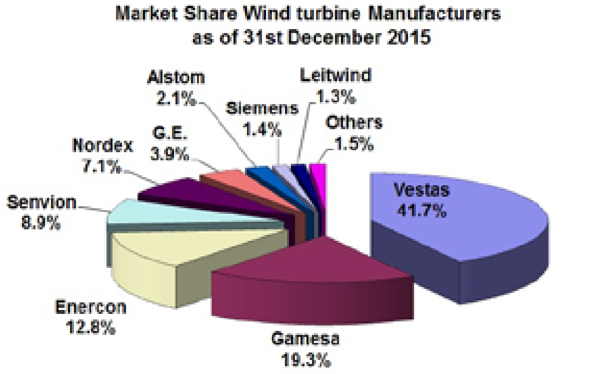


Figure 4. Overall market shares of wind turbine manufacturers in Italy at the end of 2015

In contrast to the large wind-turbine sector, Italian firms have a significant presence in the small-sized wind turbine market (i.e., turbines having a capacity up to 200 kW). The Italian companies account for half the wind turbines and components manufacturers and the entirety of producers and sellers of energy by small wind energy conversion systems.

The Italian wind energy market is quite fragmented. Players with high amount of installed with capacity are Erg Renew and Enel Green Power. Moreover, significant capacity is held by E.ON., E2i, Falck Reneables, Fri-El in joint venture with RWE, Api Nova Energia, Veronagest, Alerion Clean Power, IVPC, Tozzi. ANEV is the main association of energy producers and manufacturers in the wind sector in Italy.

### 3.3 Operational details

The 136 new wind turbines installed in 2015 have an average capacity of 2,170 kW. As a consequence, the cumulative number of online wind turbines rose to 6,484 (including decommissioned turbines) with an overall average capacity per turbine of 1,380 kW. All the plants are land-based; hill or mountain sites are typical for Italian wind farms.

Twenty seven plants were grid-connected in 2015. The average capacity of these new wind projects is approximately 10 MW. However, two different categories can be identified: half of the plants are larger 5 MW and nearly all the rest are smaller than 1 MW. The largest projects built in 2015 are Cancellara (42 MW), Banzi (30 MW), and Matera2 (29.7 MW), all located in Basilicata region.

### 3.4 Wind energy costs

For 2015 an average capital cost of 1,500 EUR/kW (1,632 USD/kW) has been estimated, which is similar to costs in previous years. This cost shows a large variability in the Italian context. It is about 20% higher than average European installation cost, because of the Italian site characteristics and the extra costs induced by the permitting procedures length and complexity.

RSE estimated the average levelised cost of energy (LCOE) for land-based wind farms installed in Italy. The LCOE results in the range 106–159 EUR/MWh (115–173 USD/MWh). The reference value of 127 EUR/MWh (138 USD/ MWh) refers to 1,750 average annual equivalent hours, slightly higher than the capacity factor registered in 2015.

# 29 Italy

## 4.0 R, D&D Activities

### 4.1 National R, D&D efforts

R, D&D activities have been carried out mainly by CNR, ENEA, RSE, and universities. CNR's activity in wind energy involves eight institutes and is in the frame of National and EU FP7 projects. The main topics are as follows:

- Wind conditions; atmospheric boundary layer research on offshore, coastal, and complex terrain, extreme winds (ISAC)
- Atmospheric and ocean interaction modeling from climate to high resolution (ISAC and ISMAR)
- Offshore and land-based wind mapping using models and spaceborne measurements (ISAC and IREA)
- Forecast of wind power production at different time horizons (ISAC)
- Aerodynamics including characterization and modeling of flow around a wind turbine and wakes (INSEAN)
- Environmental impacts and noise (IDASC)
- Offshore deployment and operations including the interaction of offshore wind parks with ocean circulation and geological risk assessment related to development of offshore wind parks (ISAC, ISMAR, ITAE and INSEAN)
- Wind generator emulators, DC/DC converter and control schemes for grid integration (ISSIA-ITAE); and
- Innovative materials (ISTEC).

CNR participates in the FP7 EU projects Towards Coast to Coast Networks (COCONET) ending in 2016, Marine Renewables Infrastructure Network (MARINET), and Integrated Research Program on Wind Energy (IRPWIND), a Wind Energy Joint Program that is part of European Energy Research Alliance (EERA).

ENEA has been working with its wind tunnel facility on aerodynamic studies of vertical-axis wind turbines. Moreover, ENEA has been involved in defining methods of validation of in-situ non-destructive testing of small wind turbine blades; an x-ray high-resolution computed tomography system is used in the laboratory. The goal is to calibrate in-situ non-destructive testing techniques to perform quantitative analysis of defects inside the component. This kind of calibration has already proved useful in the quality control stage of production in a small wind turbine factory.

RSE has been doing research on wind energy mainly under its contract agreement with the Ministry of Economic Development for research on the electrical system. Wind energy has been allotted a total commitment of 0.50 million EUR (0.54 million USD) for 2015. Main issues concern forecasting, grid integration, resource assessment through measures and models, and the project of an empowered wind and renewable atlas (Italian Wind Atlas http://atlanteeolico.rse-web. it/viewer.html).

The POLI-Wind group of the Department of Aerospace Science and Technology of the Polytechnic of Milan has been working on wind turbine aero-servo-elasticity, blade design, load mitigation, and advanced control laws. POLI-Wind has developed a wind tunnel testing facility, which includes actively controlled and aeroelastically-scaled wind turbine models for the simulation of wind farms and the study of wake interactions. The Department is also member in two major FP7 EU funded projects (INNWIND and AVATAR), which study advanced technologies for very large wind turbines in the 10–20 MW range designing new blades equipped with passive control systems for load alleviation. The POLI-Wind group is also supporting Italian and international industrial partners in the design of wind turbines.

The Department of Mechanical Engineering has a partnership in the H2020 project LIFES50+ on floating substructures for 10-MW wind turbines at water depths greater than 50 m and a partnership in the IEA Wind Task 30 OC5 on code comparison for validation against scaled and full scale offshore substructures data. The Department of Electronics, Information and Bioengineering (DEIB) has been working on power electronics and electrical generator design and on the analysis of integration of wind power system with the grid and storage systems, while the Department of Energy is working on grid and wind energy economics. The Polytechnic of Milan is part of the European Academy of Wind Energy (EAWE) as national node member, and the European Energy Research Alliance (EERA) Joint Program on Wind Energy as associate member.

The Department of Mechanical and Aerospace Engineering (DIMEAS) of the Polytechnic of Turin deployed a prototype of a floating offshore wind turbine at Cannobio, in the Lake Maggiore in March 2015. The 3-kW horizontal-axis wind turbine equipped with collective blade pitch control was mounted on a mass stabilized spar buoy floater. The plant is connected to the seabed via a three-leg compliant mooring line. The plant provided operational data used to assess bigger scale ocean-like plants and to validate the numerical models. The Department of Energy (DENERG) has been working on models of wind energy conversion and on the comparison between statistical data of wind resources and weather forecasts for the prediction of power injection into the grid.

The Inter-University Research Center on Building Aerodynamics and Wind Engineering (CRIACIV) works on the development of accurate simulation tools for large fixed-bottom offshore wind turbines, with particular emphasis on the effects that nonlinear waves produce on the dynamic structural response and associated loads. Additional ongoing research is aimed to study the coupled behavior of floating offshore wind platforms. In this research framework, CRIACIV collaborates with CNR-INSEAN and other national and international research institutions.

CRIACIV is partner of FP7 EU project MARINET, the H2020 MSCA-ITN-ETN AEOLUS4FUTURE project, and participates in the TUD COST Action TU1304: Wind Energy technology reconsideration to enhance the concept of smart cities (WINERCOST). CRIACIV is also partner of recently submitted research proposals, such as: PRIN 2015 FloatWind4Med: Integrated models for cost-effective design of floating off-shore wind turbines in the Mediterranean Sea, and H2020 MSCA-ITN-2016 WES4U: Wind Energy Solutions for Future Urban Areas. Currently, CRIACIV is contributing to the preparation of the proposal INFRAIA-01-2016-2017 MARINET2.

The Department of Civil, Chemical, and Environmental Engineering of the University of Genoa (DICCA) has been working on wind energy assessment in urban areas. DICCA has a monitoring network of 31 sonic anemometers and three LIDARs in the main ports of the Tyrrhenian Sea and is performing the structural monitoring of a small-size vertical-axis wind turbine in the Port of Savona. The Universities of Genoa and Perugia are collaborating in the research field of wind energy forecast, SCADA analysis, and wind farm operational performance assessment using NWP models, CFD and neural networks.

The ADAG applied research group of University of Naples "Federico II," in cooperation with Seapower Scarl, has been for long time involved in design, development, installation, and field testing of small/medium vertical and horizontal wind turbines according to IEC-61400-1 standards. Research is mainly regarding: blade design, airfoil wind tunnel test, aeroelastic behavior of the whole turbine, identification of aerodynamic characteristics from field test, wind turbine cost optimization for low wind speed sites, and optimization of composite manufacturing techniques to minimize the cost of blades.

The Department of Mechanical and Aerospace Engineering (DIMA) of the Sapienza University of Rome has been working on turbine aerodynamic and structural design. Since 2013, the Department is the headquarters of the OWEMES association (www.owemes.org). OWEMES is devoted to the promotion of off-shore wind and ocean energy sources and cooperate with several universities and research institutes in Italy (RSE S.p.A., CNR, ENEA, etc.). Several joint studies were carried out by DIMA and OWEMES and they were devoted to: definition of guidelines for the design of offshore wind parks; assessment of the more promising solutions for floating platform design; and design of advanced system for floating platform stability.

The University of Trento is active in the field of small turbine design and testing on its own experimental test field. Dedicated research on wind energy exploration in cold climates and anti-icing systems for wind turbines has been running for more than ten years.

The KiteGen Research and Sequoia Automation companies have set up a 3-MW kite wind generator in southern Piedmont for testing.

### 4.2 Collaborative research

RSE has long been the Italian participant in IEA Wind Task 11 Base Technology Information Exchange. TERNA joined Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power. RSE joined Task 28 Social Acceptance of Wind Energy Projects. In 2014, RSE and Department of Mechanical Engineering of Polytechnic of Milan joined the extension OC5 of Task 30 Offshore Code Comparison Collaboration. Within EERA's joint program on wind energy, CNR is a full participant, Polytechnic of Milan and RSE are associated participants.

## 5.0 The Next Term

The uncertainty about the incentive rules and tariffs for 2016 could continue to significantly affect the wind energy sector even for small wind plants. Large wind operators have already begun to look outside of Italy for more stable markets.

Many wind turbines installed in the last decade of last century are coming up to their end-of-life. For this reason, in November 2015 the bigger Italian wind operators, together with the National Association of Italian Municipalities (ANCI) and with an environmental association, declared that they are favorable and will foster sustainable refurbishment/repowering interventions.

**References:**

Opening photo: MATERA Wind Farm, (Photo credit: Asja Ambiente Italia S.p.A.)

Authors: Laura Serri, Ricerca sul Sistema Energetico (RSE S.p.A); Giacomo Arsuffi and Alberto Arena, the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Italy.

# 30 Japan

## 1.0 Overview

**In 2015, the total installed wind capacity in Japan reached 3,038 MW with 2,077 turbines, including 52.6 MW from 27 offshore wind turbines. The annual net increase was 244 MW. Total energy produced from wind turbines during 2015 was about 5.223 TWh, which corresponds to 0.55% of national electric demand (953.5 TWh).**

**Favorable signs reflecting a gradual rise in the annual net increase are becoming visible. There are 2.3 GW of new wind power projects that have almost finished the lengthy Environmental Impact Assessment (EIA) process and have acquired Feed-in Tariff (FIT) approval. Presently, 6–7 GW of new projects have begun the EIA process. It is apparent that the declining trends in wind farm development in Japan may be turning around.**

## 2.0 National Objectives and Progress

### 2.1 National targets

Following the issuance of the fourth Strategic Energy Plan, which the Cabinet approved in April 2014, the Ministry of Economy, Trade and Industry (METI) established the Long-term Energy Supply and Demand subcommittee. After consideration by the subcommittee, the *Long-term Energy Supply and Demand Outlook* report was approved 16 July 2015 [1]. The power source mix in 2030 was projected in the Outlook (Table 2). The share of wind power included in the power source mix in 2030 is 1.7%, corresponding to 10 GW of capacity, including 0.82 GW of offshore wind power. This means only 7 GW of new wind capacity is expected to be installed over the next fifteen years.

### 2.2 Progress

One hundred nine wind turbines totaling 244 MW were installed in 2015, and the annual net increase is 1.7 times larger than the 140 MW installed in 2014. The low growth of total capacity has continued. This may be attributed to the enforcement of the strict 2012 EIA law applied to wind farm projects. The EIA law requires developers of wind power plants that have total capacity of more than 10 MW to implement an EIA of the project. The assessment and approval process takes about four years, and it has caused some delays in wind farm projects in Japan. However, several large wind farms have finished the EIA process and are starting to operate.

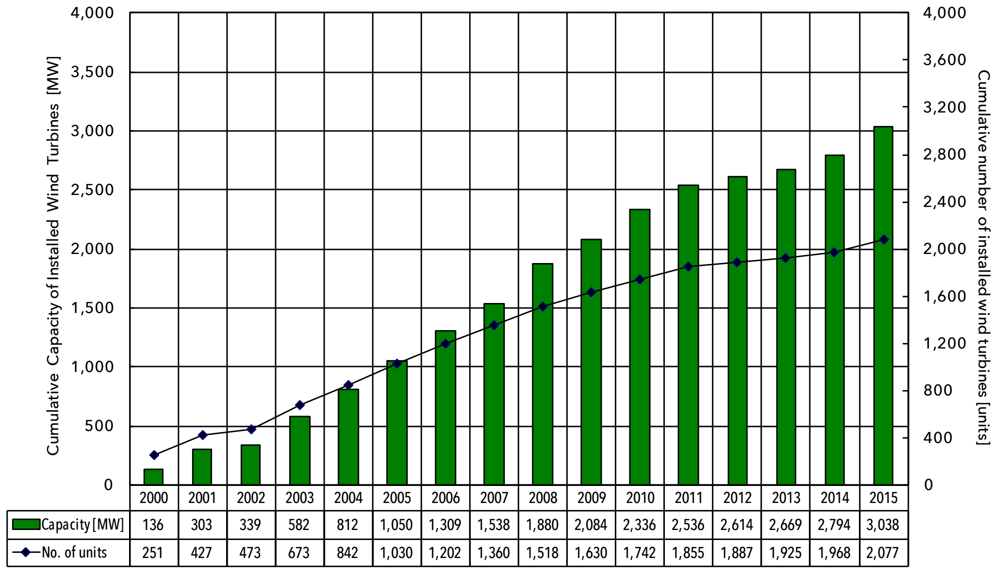
Figure 2 shows the Eurus Yurikogen Wind Farm in Akita prefecture (17 Siemens 3-MW turbines with total capacity of 51 MW), an example of a wind farm that started operation in 2015. Cumulative wind power capacity reached 3,038 MW (2,077 turbines) at the end of 2015. Total energy produced from wind turbines during 2015 was about 5.223 TWh, which corresponds to about 0.55% of national electric demand (953.5 TWh).

In 2015, 52.6 MW of offshore wind power capacity became operational. One 3-MW semi-offshore wind turbine installed 100 m offshore started operation in February 2015 at Akita port. One 7-MW offshore wind turbine with a floating foundation was installed in July 2015 as part of the Fukushima FORWARD project as described later.

### 2.3 National incentive programs

In Japan, the incentive program was changed starting in July 2012 from investment subsidies and Renewable Portfolio Standards (RPS) to the FIT scheme. At the initiation of the FIT system, the tariffs were 22 JPY/kWh (0.167 EUR/kWh; 0.183 USD/kWh) for wind power greater than or equal to 20 kW of capacity and 55 JPY/kWh (0.418 EUR/kWh; 0.456 USD/kWh) for small wind with less than 20 kW of capacity. The premium tariff for offshore wind was set to 36 JPY/kWh (0.274 EUR/kWh; 0.299 USD/kWh) in 2014. These tariffs do not include the 8% consumption tax. The duration is for 20 years for wind, including small wind and offshore wind.

The tariff will be re-assessed every year based on the latest market experience in Japan. Projects can qualify for the FIT only after the project is almost finished with the very costly and lengthy EIA process. This forces developers to spend millions before knowing whether the project will qualify for the FIT. Only a few developers with strong balance sheets can afford such uncertainty. Therefore, the Japan Wind Power Association (JWPA) has requested the government to move the FIT qualification timelines earlier in the process to make wind power development more bankable. The government has indicated its intention to give longer visibility on the FIT and could also reduce the FIT approval timing to the middle of the EIA process



| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capacity [MW] | 136 | 303 | 339 | 582 | 812 | 1,050 | 1,309 | 1,538 | 1,880 | 2,084 | 2,336 | 2,536 | 2,614 | 2,669 | 2,794 | 3,038 |
| No. of units | 251 | 427 | 473 | 673 | 842 | 1,030 | 1,202 | 1,360 | 1,518 | 1,630 | 1,742 | 1,855 | 1,887 | 1,925 | 1,968 | 2,077 |

Figure 1. Total installed wind capacity and number of turbines in Japan

### 2.4 Issues affecting growth

The onslaught of solar power installation has occupied grid connection capacity in several regions in Japan. In December 2015 the Hokkaido and Tohoku Electric Power Companies asked wind power developers to accept unlimited (formerly maximum 30 days) and unpaid curtailment. This made it very difficult for wind power developers to get financing from bankers. The JWPA continues to negotiate with electric power companies to resolve this problem. As for solar power, un-built solar power plants shall have their FIT and

| Table 1. Key National Statistics 2015: Japan | |
|---|---|
| Total (net) installed wind capacity | 3,038 MW |
| New wind capacity installed | 244 MW |
| Total electrical output from wind | 5.223 TWh |
| Wind-generated electricity as a % of national electric demand | 0.55% |
| Average national capacity factor | 21% |
| Target: | 10,000 MW |

**Table 2. Power Source Mix in 2030 in the *Long-term Energy Supply and Demand Outlook***

| Electricity Resource | Share | Capacity |
|---|---|---|
| Renewable energies | 22–24% | |
| Hydroelectric power | 8.8–9.2% | |
| Photovoltaics | 7.0% | 65 GW |
| Biomass power | 3.7–4.6% | |
| **Wind power** | **1.7%** | **10 GW** |
| Geothermal power | 1.0–1.1% | |
| Nuclear power | 20–22% | (20 power plants) |
| LNG | 27% | |
| Coal | 26% | |
| Oil | 3% | |

grid connection revoked at the latest re-estimation. This should contribute to increases in wind power capacity.

Regarding the grid line extension, METI has offered a 50% subsidy for local grid extension to four projects in Hokkaido and Tohoku for wind power as follows. In Hokkaido, the Northern Hokkaido Souden company (Eurus Energy, Eco power, etc.) grid extension is on-going and the Nippon Souden company (Softbank SB Energy, Mitsui Trading Co., Marubeni, etc.) has been suspended. In Tohoku (Akita prefecture and Aomori prefecture) the Akita Souden company (Marubeni Corporation, local banks) and Kamikita Souden company (JWD, etc.), grid extensions are on-going. In addition to the METI, the Fukushima prefecture local government intends to support local grid line extensions.

The critical inter-regional grid extension still depends on the progress of Japan's Electric Power System Reform, which is progressing gradually. Beginning in April 2016, Tokyo Electric Power Company (TEPCO) will start unbundling its power generation, transmission, and distribution businesses. This change will be nationally applied by 2020.

In 2013, three serious wind turbine accidents occurred in Japan in which the nacelles or rotors collapsed. The investigation into the cause of the accidents revealed that two accidents were caused by inadequate maintenance and repair work. The Japanese safety authority, the Electric Power Safety Division in METI, decided to implement a system for periodic safety inspections for all wind power plants over 500 kW. A similar system is widely employed for large fossil fired power plants. The Electrical Business Act was modified on 17 June 2015 and will be enacted beginning April 2017.

## 3.0 Implementation

### 3.1 Economic impact

According to an investigation report by the Japanese Society of Industrial Machinery Manufacturers, 64 companies with 69 factories and about 3,500 people were manufacturing wind turbines and their components during fiscal year 2014 [2]. Annual sales were estimated close to 103.6 billion JPY (787 million EUR; 860 million USD), this corresponds to one-third of the annual sales in fiscal year 2009. This may be due to the shrinking of the domestic market for recent few years.

Figure 2. Eurus Yurikogen Wind Farm in Akita prefecture: 17 Siemens 3-MW turbines with total capacity of 51 MW (Source: Eurus Energy Holdings Corporation)

### 3.2 Industry status

Three Japanese wind turbine manufacturers produce turbines larger than 2 MW: Mitsubishi Heavy Industries (MHI), Japan Steel Works (JSW), and Hitachi.

In the Fukushima FORWARD floating offshore wind power demonstration project, MHI's 7-MW turbine the MWT167/7.0 was installed on a three-column semi-submersible type floater at the seafront of Onahama port in July and started commissioning at 20 km offshore in September (opening photo). MHI has shifted its wind turbine business to the joint venture company MHI Vestas Offshore Wind (MVOW) and has stopped manufacturing new wind turbines.

Hitachi developed a new 5-MW downwind wind turbine, the HTW5.0-126. The first prototype machine was installed in March and started operation in September in Kamisu city, Ibaraki prefecture (Figure 3). Hitachi has reported that the downwind configuration has several merits such as passive fan-less cooling system and high reliability against extreme wind speeds with events of grid loss. A second 5-MW wind turbine is being manufactured for the Fukushima FORWARD project. It will be installed on an advanced spar type floater manufactured by Japan Marine United Corporation (JMU) and start operations in FY 2016.

JSW started manufacturing a 3-MW gearless, permanent-magnet synchronous generator (PMSG) type wind turbine, the J100-3.0.

Toshiba made a business partnership with the Korean wind turbine manufacturer UNISON in 2011. Toshiba supplies UNISON's 2-MW U88/93 turbines with medium speed gearbox, permanent-magnet synchronous generators, and develops wind farms using its world-wide business sales network. Three wind turbines were installed in Nagashima, Kagoshima prefecture, and Tomamae, Hokkaido prefecture, in 2015. Toshiba demonstrated its advanced technology "plasma aerodynamic control" (Figure 4) at the Nagashima site to increase power generation efficiency by controlling plasma-induced airflow on the blades. This technology won the JWEA Best Paper Award by the Japan Wind Energy Association (JWEA) in November 2015.

**Table 3. New Wind Turbines Developed by Japanese Manufacturers**

| Company | Model | Rated Output | Start of Operation | Type |
|---|---|---|---|---|
| MHI | MWT167/7.0 | 7.0 MW | 2015 | Digital hydraulic drive |
| Hitachi | HTW5.0-126<br>HTW2.0-86 | 5.0 MW<br>2.0 MW | 2015<br>2014 | Downwind<br>Downwind |
| JSW | J100-3.0 | 3.0 MW | 2013 (2.7 MW version) | Gearless PMSG |
| Toshiba | U88/93 | 2.0 MW | 2015 | Medium speed gear with PMSG |

Figure 3. Hitachi 5-MW wind turbine HTW5.0-126 in Kamisu (Source: Hitachi, Ltd.)

### 3.3 Operational details

The average capacity of new installed wind turbines was 2.24 MW in 2015, compared to 2.04 MW in 2014 and 1.45 MW in 2013. The estimated average capacity factor of wind turbine generation in Japan was 21% in 2015 compared to 22% in 2014, 17% in 2013, and 20% in 2012.

### 3.4 Wind energy costs

The average costs of wind energy are estimated as follows, and unchanged from 2011.

- Total installed cost: 300,000 JPY/kW (2,280 EUR/kW; 2,490 USD/kW)
- Cost of energy: 11.0 JPY/kWh (0.0836 EUR/kWh; 0.0913 USD/kWh)
- Operation and maintenance costs: 6,000 JPY/kW/unit/yr (45.6 EUR/kW/unit/yr; 49.8 USD/kW/unit/yr)
- Wind electricity purchase price: 22 JPY/kWh (0.167 EUR/kWh, 0.183 USD/kWh) for wind power greater than or equal to 20 kW of capacity, 55 JPY/kWh (0.418 EUR/kWh, 0.457 USD/kWh) for small wind, <20 kW of capacity (see Section 2.3 for details), and 36 JPY/kWh (0.274 EUR/kWh, 0.299 USD/kWh) for offshore wind power.

## 4.0 R, D&D Activities

### 4.1 National R, D&D efforts

The outline of main national R&D programs by METI, the New Energy and Industrial Technology Development Organization (NEDO), and the Ministry of the Environment are as follows.

Figure 4. Demonstration of plasma aerodynamic control technology by Toshiba in Nagashima (Source: Toshiba Corporation)

NEDO Research and Development of Offshore Wind Power Generation Technology (FY2008–FY2017) included projects titled Demonstration Research of Offshore Wind Power Generation System (FY2009–FY2016) and Demonstration Research of Offshore Wind Measurement System (FY2010–FY2016). In these projects, an offshore wind turbine and an offshore measurement platform were installed at two offshore sites each: Choshi in Chiba Prefecture and Kitakyusyu in Fukuoka Prefecture. The main purpose of these offshore R&D projects is to establish design methodology against Japan's severe offshore conditions (such as typhoons) and to demonstrate the reliability and the commercial feasibility of offshore wind turbine generation in Japan.

The NEDO project Development of Environmental Impact Assessment Method (FY2009–FY2016) published the outcomes of this research in *The basic document on environmental impact assessment of bottom mounted type offshore wind power generation (1st edition)* as the reference for developers of wind power generation. The project also published *The guide book to introduce offshore wind power generation (1st edition)*. Both of these documents were published on the NEDO homepage in September 2015.

The NEDO project Research on Next-Generation floating Offshore Wind Power Generation System (FY2014–FY2017) conducted an empirical study of floating offshore wind power generation systems in a relatively shallow area of the sea (water depths of 50 m to 100 m). The goal is to reduce the cost of floating offshore wind power generation systems.

Another NEDO project, Development of Floating Offshore Wind Measurement System (FY2013–FY2015), developed a wind profile observation system, consisting of Doppler LIDAR with inclination compensation and measurements for motion of the floating unit and waves. The data from the LIDAR on the floating unit and the tower on the breakwater were compared and the reliability of the floating LIDAR system was evaluated and demonstrated.

The NEDO project Offshore Wind Map (FY2014-2016) is developing an offshore wind database of Japanese coastal waters within 20 km of the coastline with a 500-m grid resolution. The wind database uses the mesoscale meteorological model WRF (the Weather Research and Forecasting model). The target accuracy of the simulations is to have an annual bias of less than ±5% in wind speed at a wind turbine hub height of 80 m. In addition to coastal winds, open-ocean winds are also being collected using satellite observations. Moreover, social and environmental information data which are associated with offshore wind development, such as fishing rights, shipping routes, water depths and seabed properties, are integrally stored in the database. At the end of the project, the offshore wind map browsing system will be created for accessing the GIS database consisting of wind, social and environmental information.

The Ministry of the Environment Floating Offshore Wind Turbine Demonstration Project (GOTO-FOWT PJ) (FY2010–FY2015) installed a Hitachi 2-MW, downwind turbine on a hybrid (steel and concrete) spar type floater was installed. Located about 1 km offshore from Kabashima Island in Nagasaki Prefecture, it began operation for demonstration research in October 2013. This turbine was connected to the isolated grid of Kabashima Island, and the maximum electricity demand is only 600 kW. The excess electricity produced by this turbine was used for producing hydrogen in 2015. The hydrogen was fed for fuel cells for the maintenance boat. In 2016, this floating wind turbine will be moved from Kabashima Island to Fukue Island, which has a larger population and higher electricity demand.

The METI Floating Offshore Wind Farm Demonstration Project (Fukushima FORWARD PJ) (FY2011–FY2015) installed several offshore wind turbines with various types of floaters in the Pacific Ocean more than 20 km offshore of Fukushima prefecture. A Hitachi 2-MW, downwind type wind turbine with a 4-column, semi-submersible floater and a 66-kV floating offshore electrical substation with a measurement platform were installed and began operation in November 2013. In 2015, an MHI 7-MW wind turbine with three-column, semisubmersible floater was anchored to the demonstration site in August (opening photo). A Hitachi 5-MW downwind turbine with an advanced spar type floater manufactured by Japan Marine United Corporation (JMU) will be installed in FY 2016.

A NEDO national project Advanced Practical Research and Development of Wind Power Generation is conducting R&D on advanced components and maintenance technologies applicable to next-generation, very-large wind turbines. The project began in fiscal year 2013 with the aim of further reducing the cost of wind energy. Subprojects include: Advanced Practical Development of Wind Turbine Components (FY2013–FY2015); R&D of Smart Maintenance Technologies (FY2013–FY2015); and Commercialization and Demonstration Research of Small Wind Turbine Components (FY2014–FY2016).

### 4.2 Collaborative research

Japan is participating in IEA Wind Task 11 Base Technology Information Exchange, Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power, Task 27 Small Wind Turbines, Task 28 Social Acceptance of Wind Energy Projects, Task 29 Mexnext Aerodynamics, Task 30 Offshore Code Comparison Collaboration Continuation with Correlation (OC5), Task 31 WAKEBENCH: Benchmarking Wind Farm Flow Models, and Task 32 Wind Lidar Systems for Wind Energy Deployment. Japan also participates in many maintenance teams, project teams, and working groups in International Electrotechnical Commission (IEC) Technical Committee (TC) 88.

## 5.0 The Next Term

In Japan, the cumulative installed capacity reached 3 GW, accomplishing the former national target approximately five years late. Efforts were being made to reconsider the regulations and grid concerns, which were slowing wind power development in Japan. Now favorable signs reflecting gradual increase of annual net increase are becoming visible. There are 2.3 GW of new wind power projects that have almost finished the lengthy EIA process and have acquired FIT approval. Presently, new projects totaling 6–7 GW have begun the EIA process. It seems that the declining wind farm development trend may be turning around.

**References:**

Opening photo: The Fukushima FORWARD floating offshore wind power demonstration project's 7-MW turbine MHI MWT167/7.0 in Onahama port (Source: Fukushima Offshore Wind Consortium)

[1] Ministry of Economy, Trade and Industry (METI). (2016). *Long-term Energy Supply and Demand Outlook*. www.meti.go.jp/english/press/2015/0716_01.html

[2] The Japan Society of Industrial Machinery Manufacturers (JSIM), Research report on wind turbine generation related system and device industry, in Japanese, 2016.

Author: Tetsuya Kogaki, National Institute of Advanced Industrial Science and Technology (AIST), Japan.

# 31 Republic of Korea

## 1.0 Overview

**The cumulative installed wind power in the Republic of Korea was 612 MW in 2014 and is estimated to have reached 835 MW in 2015, increasing 36% over the previous year. More than 50% of the wind turbines installed in 2015 were supplied by foreign manufacturers.**

**The Renewable Portfolio Standard (RPS) for new and renewable energy was enacted in 2012, requiring more than 3.0% of the electric power to be supplied by renewable resources in 2014 and 2015. In the third year of the RPS, more than 78% of the target rate was achieved.**

**A plan for a 2.5-GW offshore wind farm on the west coast was announced in 2010. With a nine-year construction timeline, the first stage of the project is in progress with the construction of a 60-MW wind farm. This offshore wind farm and the RPS are expected to accelerate the growth of wind energy in Korea.**

**Since 2009, the Korean government has concentrated on the local production of components to secure the supply chain and it has allocated more R&D budget to localize the component supply and develop core technologies for wind power.**

## 2.0 National Objectives and Progress

The Republic of Korea has focused on wind energy as the clean energy resource possibly replacing fossil fuels and nuclear power, and as a new area of heavy industry to escalate the Korean economy. As a result, the Korean government has increased the R&D budget continuously to support the wind turbine and component manufacturers to develop their own technologies and products. However, most heavy industry and ship building companies that had been active in the wind industry have closed because of slow technology development and the global economic crisis.

Meanwhile, the new installation of wind energy increased drastically because of the reduced restrictions for site development approval. In 2015, more than 200 MW was installed and the total is estimated to be 835 MW, 36% growth over the previous year.

### 2.1 National targets

The national target promotes renewable energy and aims to replace 11% of total energy consumption with the renewables. Currently, renewable energy production relies mostly on biomass and the Korean government is trying to reduce this dependency by focusing on wind energy and solar PV. Table 3 shows the detailed target for each resource type amongst the range of renewable energy resources. Another goal is to advance wind energy technology and boost the wind energy industry.

### 2.2 Progress

In 2015, the estimated new installation totaled 223.4 MW, increasing total wind power by 36%. In 2014, the Korean government reduced the restrictions for developing land-based wind turbine sites and simplified the approval process slightly, contributing to the increased installations in 2015.

This trend is anticipated to continue into the future. In 2016, new installations are projected to total 400 MW and the accumulated wind capacity is projected to be more than 1 GW. However, most heavy industry and ship building companies have closed their businesses because of slow technology development and the global economic crisis. Only Doosan Heavy Industry, Unison, and Hanjin are among the domestic suppliers that continue to manufacture wind turbines. Therefore, more than 50% of the newly installed wind turbines were supplied by the foreign manufacturers such as Vestas and Alstom.

The net sales in the Korean wind industry were mostly comprised of generation systems, towers, and casting components. The production of the casting components is decreasing because of market competition. However, the sales of turbine systems are steadily increasing. In 2013, turbine sales increased 70% over the previous year—an estimated 515 million USD (476 million EUR). Table 4 shows the total sales of the wind energy industry.

The number of manufacturers decreased in 2014. In 2012, 38 companies were involved in the wind energy in 2012, 44 in 2013, and 37 in 2014. The number of employees was estimated at 1,988 in 2013 and increased to 2,424 in 2014. Restructuring of the wind energy industry is under way. Companies involved in casting components have changed their business as a result of strong competition from Chinese companies. Total employment for casting components steadily decreased from 1,163 in 2009 to 347 in 2013, but employment for turbine systems increased from 236 in 2007 to 1,112 in 2013.

### 2.3 National incentive programs

The Korean government subsidizes the installation of New and Renewable Energy (NRE) facilities to enhance deployment and to relieve the end user's burden. The government has specially focused on school buildings, warehouses, industrial complexes, highway facilities, factory, and electric power plants. For wind power installation, especially for demonstrations or private use, 50% of the installation cost is compensated by the government.

Other incentive programs are as follows:

- Million Green Homes Program: in order to encourage the deployment of the renewable energy in the residential area, the government expanded the 100,000 solar-roof program to one million green homes for diversifying and optimizing renewable energy use. The target is to construct one million homes equipped with the green energy resources by 2020. By the end of 2015, 200,000 homes were equipped with the green energy and the budget was decreased significantly.
- Green energy requirements for public buildings: new construction, expansion, or remodeling of public buildings having floor area exceeding 1,000 m$^2$ are required to supply more than 10% of total energy with renewable energy.
- Feed-in Tariff (FIT): The standard price is adjusted annually reflecting the change of the NRE market and the economic feasibility of NRE. Concerning wind energy, the FIT was 0.10 USD/kWh (0.09 EUR/kWh) as a flat rate for 15 years. The FIT is applied to wind farms installed by 2011 and wind farms constructed from 2012 are supported with RPS.
- RPS: RPS was enacted in 2012 and required more than 3.0% of the electric power to be supplied with renewable resources in 2014 and 2015. This regulation applies to the electric power suppliers that provide more than 500 MW. The required rate will increase to 10% in 2024. Weighted factors for land-based wind farms, offshore farms less than 5 km from shore, and offshore farms more than 5 km from shore are respectively 1.0, 1.5, and 2.0. In the third year of RPS, 2014, approximately 78.1% of the yearly target was achieved. Some complaints about the RPS target were reported and the government reduced the burden to electric power suppliers by extending the 10% requirement from 2014 to 2022.

In addition, there are other available national incentive programs such as Loan and Tax Deduction and the Local Government NRE Deployment Program.

### 2.4 Issues affecting growth

There are two major factors escalating the growth of wind energy. The first is the construction of the 2.5-GW offshore wind farm in the west sea. According to the original roadmap announced by the government, the 2.5-GW farm would be constructed in three stages over nine years beginning in 2011. For the first four years, 100 MW of wind power would be installed to test the track record and the technology of site design. Then 400 MW will be installed for accumulating the operational experience and commercial purposes over the next two years. At the final stage, a 2-GW wind farm would be constructed with 5-MW wind turbines for commercial purposes. The total budget was estimated to be 7.5 billion USD (6.9 billion EUR). However, construction has been delayed for several reasons and the government modified the construction plan as shown in Table 6.

**Table 1. Key National Statistics 2015: Korea**

| | |
|---|---|
| Total (net) installed wind capacity | ***835 MW*** |
| New wind capacity installed | ***223.4 MW*** |
| Total electrical output from wind | 1.146 TWh (2014) |
| Wind-generated electricity as a % of national electric demand | 0.21% (2014) |
| Target: | 2% wind energy by 2035 |

***Bold italic*** indicates estimates

# 31 Republic of Korea

The other factor affecting growth is the RPS program that began in 2012. Major electric power suppliers are required to provide 3% of the electric power with renewable energy, including wind power, and the rate will increase to 10% in 2024. This regulation was expected to encourage the power suppliers to invest in the wind energy deployment and Table 2 shows its favorable effect. New installation has doubled since 2012.

In the Republic of Korea, most high mountains were strictly categorized as preservation areas and it was very difficult to get approval for new wind farm construction. But the central government has lessened the environmental protection regulations; this change simplified the wind farm approval process. Therefore, a large amount of wind power, 223.4 MW, was installed in 2015.

## 3.0 Implementation

### 3.1 Economic impact

The impact of the wind energy industry is very limited in the Korean economy. In 2014, the net sales from production totaled 943 million USD (867 million EUR) and employment was 2,424.

### 3.2 Industry status

Major shipbuilding and heavy industry companies that had been active in the wind industry have closed their businesses. Only Doosan Heavy Industry and Unison Inc. continue development but have also downsized because the cost of the Korean manufacturing is high and not competitive to the foreign suppliers. However, Doosan is developing new turbine for offshore wind farms and Unison designed a wind turbine suitable for Korean conditions which is characterized for low wind speed. Unison developed a 2.5-MW turbine which has two different tower heights and longer blades.

### 3.3 Operational details

In 2014, 89.6 MW of wind power was installed and most turbines were supplied by domestic manufacturers. Eight, 2-MW and three, 3-MW turbines were supplied by Doosan; Hyundai supplied seven, 2-MW turbines and one, 1.65-MW turbine. STX also installed one, 2-MW turbine. However, Samsung and Hyundai Heavy Industries closed their wind energy businesses, and other companies have downsized.

**Table 2. Total Installed Wind Capacity in Korea**

| Year | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Installed Capacity (MW) | 50.0 | 31.0 | 79.0 | 18.0 | 108.0 | 47.3 | 30.9 | 26.6 | 54.5 | 89.6 | 58.6 | ***223.4*** | 835.0 |
| Electrical Output (GWh) | 47 | 130 | 239 | 376 | 436 | 685 | 817 | 863 | 913 | 1,148 | 1,146 | - | - |

***Bold italic*** indicates estimates

**Table 3. National Targets of Renewable Energy Resources (% of total renewables)**

| Energy Resources | Solar PV | Solar Thermal | Wind | Geothermal | Biomass | Bioenergy | Hydro | Ocean |
|---|---|---|---|---|---|---|---|---|
| 2020 (year) | 11.1 | 1.4 | 11.3 | 2.5 | 47.3 | 17.6 | 6.3 | 2.4 |
| 2025 (year) | 13.3 | 3.9 | 12.5 | 4.6 | 40.2 | 19.6 | 4.3 | 1.6 |
| 2035 (year) | 14.1 | 7.9 | 18.2 | 8.5 | 29.2 | 17.9 | 2.9 | 1.3 |

**Table 4. Total Sales of the Wind Energy Industry in Korea**

| Year | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|
| Total Sales (million USD; million EUR) | 526 | 1,099; 1,010 | 912; 838 | 826; 756 | 857; 788 | 1,085; 997 | 852; 783 | 943; 867 |
| Growth Rate (%) | - | 108 | -18 | -10 | 3 | 26 | -22 | 10 |

**Table 5. Number of Employees in the Wind Energy Industry**

| Year | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|
| Turbine System | 236 | 312 | 727 | 957 | 1,021 | 1,000 | 1,112 | 1,159 |
| Casting Components | 925 | 1,193 | 1,163 | 1,032 | 810 | 431 | 347 | 396 |
| Total | 1,434 | 1,860 | 2,332 | 2,554 | 2,456 | 2,030 | 1,988 | 2,424 |

**Table 6. 2.5-GW Offshore Wind Farm Construction Plan**

| | Demonstration | Standardization | Deployment |
|---|---|---|---|
| Objective | Test set up, track record, and site design | Operation experience, validation of commercial operation | Cost effectiveness per GW, site development, commercial operation |
| Wind Power Installed | 60 MW | 400 MW | 2,000 MW |
| Schedule | 2011–2018 (7 years) | 2019–2020 (2 years) | 2021–2023 (3 years) |

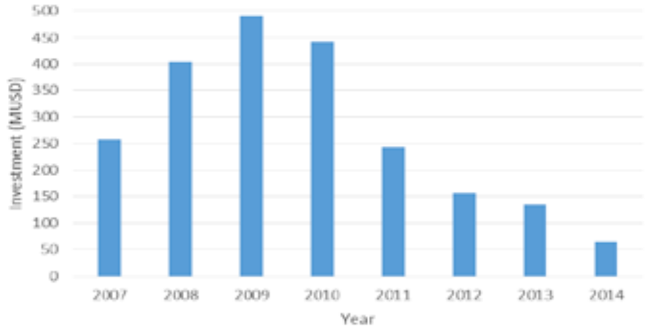


Figure 1. The budget trend of government sponsored R, D&D (million USD)

### 3.4 Wind energy costs

Newly installed wind turbines, especially those supplied by domestic manufacturers, are not operated for commercial purposes but for system checks and to gain experience. Therefore, there is limited electric output recorded and it is still difficult to estimate the real cost of wind energy in Korea.

## 4.0 R, D&D Activities

### 4.1 National R, D&D efforts

Investment in the wind energy industry has been falling continuously after its peak in 2009. However, new installations increased drastically in 2015 and are expected to continue in 2016. This new trend is expected to produce new investment for wind energy in Korea.

## 5.0 The Next Term

Korea's optimistic vision for wind energy has been diminished by bad wind conditions, small land area, strong environmentalists, opposition from local communities and government, and other issues. Also, several major turbine developers have closed their businesses because of slow technology development, severe competition with Chinese companies, etc. However, the RPS provides motivation for renewable energy investment as construction on the 2.5-GW offshore wind farm resumes in 2016 and new installation of more than 400 MW of wind energy expected in 2016. These factors will support Korean wind energy deployment for the near future.

**References:**

Opening photo: Hwasun Wind Farm (Source: Unison Co., LTD)

Authors: Cheolwan Kim, Korea Aerospace Research Institute and Sang-geun Yu, Korea Energy Management Corporation, Korea.

# 32 México

## 1.0 Overview

**México is one of 26 countries in the world with more than 1,000 MW of installed wind power. In 2015, México added 714 MW of new wind power to the existing 2,551 MW installed, bringing the total to 3,073 MW. This wind energy comes from 1,789 turbines over 37 wind farms located in Oaxaca, Baja California, Chiapas, Jalisco, Tamaulipas, San Luis Potosí, and Nuevo León regions [1].**

**In 2015, approximately 714 MW of new capacity were installed in seven wind farms, three of which were sited in Oaxaca [2]. See Table 2 for additional details. Wind turbine suppliers were Gamesa (266 MW), Acciona (175.5 MW), Vestas (170.1 MW), and Alstom (102 MW).**

**México's largest wind energy resource is found in the Isthmus of Tehuantepec in the state of Oaxaca. With three new installations becoming operational in 2015, Oaxaca now has 27 wind farms totaling approximately 2,360 MW on installed capacity. The Instituto de Investigaciones Eléctricas (IIE) operates a test center in this region (Figure 1).**

## 2.0 National Objectives and Progress

In December 2013, México's Energy Reform legislation was enacted to transform the state-owned utility into a free market. This conversion consists of creating independent generation, transmission, and retail companies, as well as a wholesale market. In July 2014, the Mexican government created the National Energy Control Center (CENACE) as the independent system operator [3, 4]. The results of the first auction under this new system are expected in March 2016. These reforms are expected to generate rapid growth with at least 2,500 MW per year expected to be installed in 2017 and 2018 [1].

The Sustainable Energy Fund was created by the Secretariat of Energy (SENER) and the National Council for Science and Technology (CONACYT), under the mandate of the Law for Science and Technology. The Sustainable Energy Fund sponsored the Mexican Wind Energy Innovation Center (CEMIE-Eólico). The main purpose of the CEMIE-Eólico is to increase and consolidate the country's scientific and technical capacities in the field of wind energy by means of building synergy among national institutions so that activities on innovation, research, and technology can be oriented towards the construction of a stronger national wind energy industry. The CEMIE-Eólico is a consortium led by the Instituto de Investigaciones Eléctricas and consists of six public research centers, 14 universities, and ten private companies. The CEMIEEólico started operations in 2014, developing 13 projects that will be carried out over the following four years.

Figure 1. The Wind Turbine Test Center operated by the Instituto de Investigaciones Eléctricas

| Table 2. New Wind Installations in 2015 [2] | | | |
|---|---|---|---|
| Project | Region | Manufacturer | Capacity (MW) |
| Dominica Fase I y II | San Luis Potosí | Gamesa | 200.0 |
| Energía Sierra Juárez | Baja California | Vestas | 155.1 |
| VENTIKA I | Nuevo León | Acciona | 126.0 |
| Sureste I Fase II (Energías Renovables La Mata) | Oaxaca | Alstom | 102.0 |
| PIER II Quecholac Felipe Ángeles | Puebla | Gamesa | 66.0 |
| Pe Ingenio | Oaxaca | Acciona | 49.5 |
| Granja SEDENA | Oaxaca | Vestas | 15.0 |
| **Total** | | | **713.6** |

**References:**

Opening photo: Eurus wind farm with 167 wind turbines located in LaVenta, in Juchitán de Zaragoza, Oaxaca

[1] Global Wind Energy Council (GWEC). 2016. "Global Wind Report 2015: Annual Market Update."

[2] Mexican Wind Power Association (AMDEE). Accessed June 2016, www.amdee.org

[3] www.dof.gob.mx/nota_detalle.php?codigo=5357927&fecha=28/08/2014

[4] National Energy Control Center (CENACE) www.cenace.gob.mx/29 México

| Table 1. Key National Statistics 2015: México [1] | |
|---|---|
| Total (net) installed wind capacity | 3,073 MW |
| New wind capacity installed | 714 MW |
| Total electrical output from wind | 7.3 TWh |
| Wind-generated electricity as a % of national electric demand | 3.2% |
| Target: | 9.5 GW of wind power by 2018 |

# 33 the Netherlands

## 1.0 Overview

**Regarding changes in policies and politics, 2015 was calm year. The main drivers for the national energy policy are the EU objective of 14% renewable energy in 2020 and the "SER Agreement" (2015) which defined five objectives:**

- **A reduction in final energy consumption averaging 1.5% annually—this is expected to be more than enough to comply with the relevant EU Energy Efficiency Directive;**
- **A 100 petajoule (PJ) saving in the country's final energy consumption by 2020;**
- **An increase in the proportion of energy generated from renewable sources from 4.4% in 2015 to 14% in 2020, in accordance with EU arrangements;**
- **A further increase in proportion of energy generated from renewable sources to 16% in 2023;**
- **At least 15,000 additional full-time jobs.**

**The SER Agreement also contains guidelines for feedback and for adjusting the implementation. Offshore wind energy targets were redefined and are listed in Table 2.**

## 2.0 National Objectives and Progress

### 2.1 National targets

The existing 357 MW of installed offshore capacity (Egmond aan Zee, Princes Amalia, Luchterduinen) combined with approximately 600 MW under construction (Gemini) and the deployment as defined in the SER Agreement (3,500 MW) will bring the total to approximately 4,450 MW installed offshore wind capacity in 2023. The SER Agreement sets intermediate targets for offshore installations between 2019 and 2023, and a 6,000 MW target for land-based wind for 2020. However, no intermediate target is mentioned for land-based wind.

Since social acceptance is a major bottleneck in the deployment of land-based wind energy, the SER Agreement describes tools to enhance the acceptance of wind energy—project developers will be obliged to maximize acceptance by law. One of the tools included is the option for citizens to participate financially. Furthermore, multifunctional spatial use is compulsory, for example installing wind energy along dikes and dams and near sluices.

### 2.2 Progress

The Netherlands had net installation of 511 MW in 2015. This consisted of 382 MW of land-based and 129 MW of offshore installations. Net land-based installation figures include 442 MW of new capacity, approximately 60 MW decommissioned, and the remainder being repowered.

For land-based wind, the trend is moving from smaller wind turbines (1-MW class) toward the larger 3-MW class. Projects in progress larger than 10 MW are in Delfzijl (19, 3-MW turbines), Hellegatsplein (four, 3-MW turbines), Nieuw Prinsenland (four, 3-MW turbines), Zuidereehaven (four, 3-MW turbines), Rotterdam (three, 5-MW turbines) and NoordOostpolder (20, 7.5-MW and 17, 3-MW turbines). The set of 17 wind turbines at NoordOostpolder are placed in Lake IJsselmeer at an approximate depth of 5 m.

### 2.3 National incentive program

In 2011, the system of SDE+ subsidy was introduced and since then, the system has been fine-tuned further. In principle the SDE+ system requires the applicant to define a certain 'claimed energy price' (misleading term in SDE+: 'basis price' or 'basis tariff'). The basic price is the final price which the applicant wants to receive for their generated renewable energy. To obtain this final price the renewable energy producer is assumed to receive a (more or less fixed) pay back price from the utility. The SDE+ fills the gap between the pay back price and desired final price (basis tariff).

The basic principle of the SDE+ is that every generation technique has its own maximum allowed basis tariff and the cheapest option will be granted first. Applications can be submitted for the SDE+ more or less throughout the year. However, applications done earlier in the year will receive a lower SDE+ subsidy, but a higher chance for grant approval. Offshore wind energy is excluded from this system and is expected to get its own subsidy program in the spring of 2016. In 2015, the SDE+ subsidy system for land-based turbines was split up into several categories: wind on land, wind on land replacements, wind on dikes, wind in lakes, and a category for special cases.

The maximum SDE+ subsidy is now dependent on the category (e.g., wind on land replacement), windspeed, and when the application is submitted. For example, a third round submission in May would have had a fixed basic tariff. Instead, the basic tariff depends on the local wind speed. The higher the wind speed, the lower the basis tariff (equal to the overall electricity price of the wind energy) and the lower the SDE+ subsidy, equal to the gap between pay back tariff and basis tariff. As in previous years, the SDE+ subsidy is not only applicable to renewable electricity, but also for green gas and renewable heat including geothermal heat. All applications for wind in 2015 were completed in July or earlier, meaning they were submitted for lower tariffs.

### 2.4 Issues affecting growth

It was difficult for wind energy to receive SDE+ subsidies during the first few years of the SDE+ subsidy program because there were many renewable energy projects applying for a lower tariff than the tariffs of the cheapest wind energy projects. In 2012, only 2.0 million EUR (2.2 million USD) were granted for one wind project and most of the money went to other kinds of renewable energy projects. This was, up to 2012, a major factor limiting the growth of wind energy. After three years of applying the principle of 'the cheapest renewable energy option first,' most of the low hanging fruits have been plucked and in 2015 land-based wind claimed approximately one-eighth of the SDE+ budget.

Although there are, from a financial point of view, good arguments to limit the SDE+ subsidy to a maximum number of full load hours per year; this discourages investors from using turbines with relatively oversized rotors. Discussions are going on to correlate this limit not to the size of the generator but to the size of the swept area.

With a characteristic price of around 140 EUR/MWh (152 USD/MWh), offshore wind energy is far out of the region of tariffs where it can get SDE+ subsidies. Therefore, no applications for offshore wind projects have been done. Special tenders for offshore wind SDE+ are expected to open in April 2016.

Bottlenecks on for land-based wind energy are being monitored. The main bottlenecks are social acceptance, as well as hindrance and interferences with other land uses. Having a land area of only 41,000 $km^2$ and a population of 17 million, the Netherlands is densely populated. Noise and so called 'horizon pollution' (visual impacts) are issues raised on nearly every project. To broaden the basis of public support, a code of conduct has been drawn up. One of the more important tools in this code is enhancing the possibilities for people living in the neighborhood to participate financially in the wind energy projects. Public acceptance also plays a role concerning the illumination of wind turbines surrounding airports. The provinces of Noord Holland and Flevoland have high wind energy potential but also have the Schiphol airport landing corridors, and wind turbines are often illuminated—a serious visual impact. A project began in mid-2014 to reduce this illumination.

The limited availability of good wind locations also affects growth. Several issues can contribute to this. Interferences with Natura 2000, an EU-established network of nature protection areas, might limit the size of some new, intended wind farms. The use of dikes and river foreland for wind energy had usually been forbidden in the past, but are now occasionally allowed. Less strict, but also clearer regulation can lead to more available spaces and faster decision making. The first project on a sea dikes in the Netherlands is expected to be built in 2016.

In a project to find more suitable locations scanned for local options for wind energy local governments, project developers, and utilities collaborated on finding locations that could be easily connected to the grid. The starting point in this methodology is the grid and this collaboration makes it easier for project developers to plan their projects where the construction of the farm coincides with intended reinforcements of the grid.

Recently reduced fiscal advantages for private citizens on green savings accounts, green bonds, and green stocks resulted in reduced amounts of money available for banks to spend on green projects. In addition, the general tendency of banks, pension funds, and insurance companies is to act according to stricter rules on financing of projects

**Table 1. Key National Statistics 2015: the Netherlands**

| | |
|---|---|
| Total (net) installed wind capacity | 3,376 MW |
| New wind capacity installed | 511 MW |
| Total electrical output from wind | 7.5 TWh |
| Wind-generated electricity as a % of national electric demand | 6.3% |
| Average national capacity factor | 25.6% |
| Target | 14% renewable energy in 2020 |

# 33 the Netherlands

**Table 2. Offshore Wind Energy the Targets Defined in the 2015 SER Agreement**

| Call for tender (year) | Additional offshore wind power (MW) | Became operational (year) |
|---|---|---|
| 2016 (early) | 700 | 2019-2020 |
| 2016 (late) | 700 | 2020 |
| 2017 | 700 | 2021 |
| 2018 | 700 | 2022 |
| 2019 | 700 | 2023 |
| **Total** | **3,500** | |

(e.g., Basel III and Solvency II are obligatory) also leading to less money being available to spend on green projects. Both effects result in the need for higher financial participation of the project owner, making projects more difficult to develop.

To avoid lengthy permit procedures the RijksCoordinatieRegeling (National Coordination Regulation) exists. This means for wind energy projects >100 MW, the national government automatically takes over procedures and deals the permissions. This regulation coordinates and shortens procedures and is meant to speed up deployment.

For offshore wind a completely new system of tendering is under development. This deployment system is based on the SER agreement which describes a plan for five years of tendering 700 MW per year. Project developers no longer choose their favorite locations. Instead, the government chooses locations and organizes tenders for projects of 350 MW, and project developers can offer bids.

A legal framework is being developed for these tenders during the period 2014–2016. Many acts, decrees, and orders have been adapted, for example: a water decree, ministerial orders for water and offshore wind energy, wind farm site decisions, implementing regulations for offshore wind energy, and acts on water, offshore wind energy, and subsidies. This whole system will in 2016—after tendering—lead to agreements on connection and transmission and agreements on realization and along with site permits and SDE+ grants. These agreements, permits, and grants will make it possible for the winning tender bidder to build, and operate an economically feasible offshore wind farm.

To speed up the whole process, simultaneous to the adaption of the legal framework, a set of site investigations have been carried out. These studies are usually done by tender bidders. In close cooperation with the market, the Ministry of Economic Affairs/RVO took the lead to complete a set of six desk studies (geology, UXO, archaeology, wind resource, metocean, and morpho-dynamics) and two surveys (geophysical and geotechnical) in the first tender area, the Borssele Wind Farm Zone. An advantage is that instead of all tender bidders doing all these investigation by themselves—leading to high costs per bidder—the work is centralized and executed once. The government pays for these site studies and expects to recover the investment via a smaller SDE+ subsidy resulting from a lower bid price.

## 3.0 Implementation

### 3.1 Economic impact

The total 2015 investment in wind energy in the Netherlands is estimated at 620 million EUR (675 million USD). This assumes an average investment cost for land-based wind of 1,376 EUR/kW (1,497 USD/kW) for the 449 MW installed. The total investment in wind energy installations built up through 2015 is estimated at over 5.0 billion EUR (5.4 billion USD.)

In 2014, a report about the economic impact of the wind sector on the Dutch economy was published. This was the result of extensive research covering 236 companies. Based on this research, the direct employment in the sector was estimated at 5,450 jobs, with 26% of this in the construction sector, 20% in the commercial service sector, 19% in the energy sector, 10% in industry, 10% in the financial service sector, and 8% in transportation. The whole sector has a direct turnover of 2.57 billion EUR (2.80 billion USD), with a gross added value of 864 million EUR (940 million USD). When indirect impacts are taken into account, these values are much higher—total employment of 7,950 full-time jobs, total turnover of 3.06 billion EUR (3.33 billion USD), and an added value of 1.147 billion EUR (1.25 billion USD).

Although difficult, an attempt has been made to divide the economic turnover between land-based and offshore, as well as and operation and maintenance versus development. Most noticeable is the high turnover for offshore compared to land-based. Although only 228 MW (~8%) of the installed wind capacity is offshore, the offshore sector accounts for approximately 60% of the turnover. This indicated that offshore wind is a typical export product for the Netherlands and that most of this turnover is realized abroad.

Figure 1. The last wind turbine being placed in Lake Ijsselmeer at the Westermeerwind/Noordoostpolder wind farm

Of the enterprises interviewed 75% expected an increase of the turnover in the next five years. Mentioned causes for this were not only the expected end of the economic crisis, but also foreign policy and the renewed Dutch wind policy. Of the interviewed enterprises 25% had serious difficulties finding workers. The research was carried out in 2013, during the lowest point of the economic situation and this percentage is very high with the average through the whole economy around 6% in 2013.

### 3.2 Industry status

Dutch turbine manufactures are gradually rebounding. Most notably, in 2015 a 140-m diameter, 6-MW, two-bladed, downwind 2B Energy offshore wind turbine was erected. This new model was developed from scratch and is constructed as lean and robust as possible, while simultaneously making use of proven components. The first turbine was placed near a sea dike in Eemshaven. It is now producing power to the grid and in the certification phase (Figure 2).

The Lagerwey Company has its roots in the late 1970s, was the first developer of the DirectDrive, and is active in the 2.0–3.0 MW range of turbines. The company developed a new 93-m, 2.6-MW turbine and is taking orders from abroad. The turbine operates at variable speeds and, because it is high efficiency, natural airflow is sufficient for cooling rather than artificial cooling for the generator. Development of a new Lagerwey L136 continued through 2015. This machine will have a 3.8-MW generator and a 136-m rotor at a hub height of 133 m. A 150-m rotor version at 150-m hub height will be developed later.

Emergya Wind Technologies has doubled its production and is producing dozens of turbines in the 0.5–1.0 MW class, mainly for the UK, but also for Alaska in the United States. All Emergya turbines are designed for IEC61400 wind class IIA or IIIA.

**Table 3. Direct Turnover of Dutch Enterprises for wind energy Activities in 2013 (including activities abroad)**

| Category | Land-based | | Offshore | | Total | |
|---|---|---|---|---|---|---|
| | Million EUR; Million USD | % | Million EUR; Million USD | % | Million EUR; Million USD | % |
| Development | 67; 73 | 3; | 429; 467; | 21 | 496; 540 | 24 |
| O&M | 791; 861 | 38 | 797; 867 | 38 | 1,588; 1,728 | 76 |
| Unknown | | | | | 486; 529 | |
| Total | 858; 934 | 41 | 1,226; 1,334 | 59 | 2,084; 2,267 | 100 |

Besides these turbine manufactures, many supply companies or companies de¬livering transport, installing services, or delivering knowledge services (controlling, aerodynamics, strength calculations, etc.) are present in the Netherlands. Larger companies include Ballast Nedam/VanOord and Smulders. Smaller companies in the knowledge sector are less well known, but the Netherlands has a strong position in this market as well.

Europe's largest commercial wind turbine test site is located in the Flevoland polder. This Lelystad test site has room for 12 separate positions, nine of which are available for prototypes with a maximum tip height of 200 m.

### 3.3 Operational status

The wind index is a method used to evaluate wind plant performance over the year. Although it is difficult to compare from year to year and wind indices in the long term have a variable basis, 2015 had a wind index of 102% (compared to 89% in 2014 and 91% in 2013). This was the first year of a wind index greater than 100% since 2008. December 2015 was the windiest month with a wind index of 192%.

Given these facts, the capacity factor on land in 2015 was 25.6%. This is significantly higher than the last 10-year average capacity factor of 21.4%. The wind index of nearly 100% indicates that newer turbines on land are performing better than the older ones. Key factors to this are the increased average hub height and the increased swept-area-to-power ratio. Offshore, the capacity factor in 2015 was nearly 40% (2014: 37.5%).

### 3.4 Wind energy costs

Every year the cost of wind energy is calculated to determine the SDE+ tariff. As described in section 2.3, the cost of wind energy is split up in categories and wind regimes. The maximum costs that can be subsidized are in the following ranges:

- For new wind turbines: 98 EUR/MWh; 107 USD/MWh for wind speeds <7.0 m/s and 74 EUR/MWh; 81 USD/MWh for >8.0 m/s
- For replacement: 74 EUR/MWh; 81 USD/MWh for wind speeds <7.0 m/s and 53 EUR/MWh; 58 USD/MWh for >8.0 m/s
- For turbines installed on sea dikes: 107 EUR/MWh; 116 USD/MWh for wind <7.0 m/s and 81 EUR/MWh; 88 USD/MWh for >8.0 m/s

New offshore wind projects in 2016 are supposed to be below 124 EUR/MWh (135 USD/MWh), excluding the offshore HV station and the further connection to the grid.

## 4.0 R, D&D Activities

### 4.1 National R, D&D efforts

Since 2012, R&D programs for wind energy have only focused on offshore wind energy. These programs are coordinated by the Topconsortia for Knowledge and Innovation (TKI Wind Offshore), which represents the R&D community and the industrial sector. A major driver behind this structure is to have the business sector, research centers, and

Figure 2. The 2B Energy 140-m, 6-MW downwind wind turbine in Eemshaven

universities directing R&D efforts, instead it being directed by politics and governmental organizations. Further, the intention is to support co-operation among these parties. The R&D community is encouraged to work more in line with requests from the industrial sector and in turn the industrial sector is encouraged make greater use of the knowledge available in the research centers and universities. Besides coordinating the subsidy flows for R&D according EU legislation, the TKI receives a basic subsidy for coordinating tasks. TKI can receive a bonus subsidy based on the extent of the industrial sector and R&D institutes' cooperation.

In 2015, there was one R&D tender with a subsidy budget of 4.5 million EUR (4.9 million USD). The tender was oversubscribed. On average, the projects were subsidized at a rate of approximately 70%, because most of the projects awarded had a fundamental research or industrial research profile. The government is reducing this percentage down to approximately 50%.

The more general Renewable Energy subsidy program was also completed in 2015. In total, around 20 new R&D projects on wind energy started. An overview of all granted projects can be found at [1] and [2]. Examples include:

- *Project Prototype Z-bridge*—a project in which a transfer system for man and goods (up to 1,000 kg) is being developed, as shown in Figure 3.
- *Underwater Noise Abatement System for Pile Driving*—a system of hollow chambers containing trapped air that act as Helmholtz resonators. The whole system lowers down to the seabed level similar to a Venetian blind system and reduces under water noise during construction.
- *Hydraulic Mechanical Transmission*— a project where the drive train of a 4-MW land-based turbine will be replaced by hydraulic transmission using the "Floating Cup Technology." The objective is to have the technology on the market in 2018.
- *Loadwatch*—development the FOBM fiber-optic measurement system and to make it ready for commercial sales. The system monitors loads on offshore wind turbines that can be directly used as input for condition-based maintenance and individual pitch control. It is expected that the project will result in a reduction of cost of energy of 0.4%.
- *C-Tower*—a project to demonstrate the feasibility of replacing a steel tower with a fiber-reinforced composite structure. The aim is to reduce maintenance and thereby the life cycle cost of the entire wind turbine. Production costs will be reduced by using automated production techniques.
- *S4VAWT*—design of a semi-submersible floater for a large vertical axis turbine. The floater is designed using integral design, as shown in Figure 4.

Figure 3. Z-bridge, a newly developed transfer system enabling transfer of goods and workers in wave heights up to approximately 3 m

### 4.2 Collaborative research

The Netherlands continued to play an important role in several IEA Wind tasks. These include Task 26 Cost of Wind Energy with the representative of the offshore wind sector, TKI, participating. Participation in the IEA Wind tasks has proven to be a cost-effective way to conduct research. In 2015 the Netherlands joined Task 37 Wind Energy Systems Engineering: Integrated R, D&D. On average, 1 EUR (1.088 USD) spent in the Netherlands on research gives access to a value of 5 EUR (5.44 USD) of research spent in the other participating countries.

### 4.3 Offshore deployment

Offshore deployment information, including site investigation reports, project and site descriptions and information on workshops can be found at http://offshorewind.rvo.nl/.

## 5.0 The Next Term

### 5.1 Deployment

In 2016, two 700-MW tenders of for offshore wind will open and close. The levelized cost of energy is limited to 124 EUR/MWh (135 USD/MWh) excluding the costs of the HV station and further connection to the grid. The first wind turbines in the Gemini Wind Farms, (two farms of 300-MW each) are expected to be placed 85 km off the north coast of the Netherlands. In the beginning of 2016, 832 MW of land-based wind power were in the construction phase, a portion of which will be finished in 2016.

Figure 4. Semi-submersible floater for a large vertical axis turbine being designed by ECN

### 5.2 Innovation Contract/TKI

In 2016, continuation of work under the guidance of TKI Offshore Wind is foreseen. A new tender is expected with criteria defined in close cooperation with the market but evaluated by independent experts. Central criteria for the tenders are the reduction on cost of energy and the economic impact on society.

### 5.3 SDE+ in 2015

The total budget will more than double and increase to 8.0 billion EUR (8.7 billion USD). No major changes are expected but there will be some fine-tuning, for example, measures are taken to discourage early dismantling of wind turbines to receive subsidy for replacing wind turbines.

**References:**

Opening photo: Dutch cows in the foreground of a wind turbine (Photo credit: André de Boer, RVO)

[1] www.volginnovatie.nl
[2] www.tki-windopzee.nl
[3] www.rvo.nl/onderwerpen/duurzaam-ondernemen/duurzame-energie-opwekken (Dutch)

Author: André de Boer, Rijksdienst Voor Ondernemend Nederland (Netherlands Enterprise Agency), The Netherlands.

# 34 Norway

## 1.0 Overview

**In 2015, 17 MW of new wind power capacity was installed in Norway. By the end of the year, the total installed capacity was 873 MW and production of wind power reached 2,511 GWh, compared to 2,214 GWh in 2014. The calculated wind index for Norwegian wind farms in 2015 was 109%, corresponding to a production index of 113%. The average capacity factor for wind farms in normal operation was 35%. Wind generation amounted to 1.7% of the total electric production in the country and offset 1.9% of total demand.**

**Electric energy generated in Norway includes a high share of renewable energy. The primary source of electricity is hydropower, generating approximately 96% of the country's electricity in 2015—exceeded demand by 8.6 TWh. In recent years wind power has also gained interest as a commercial source of energy. Norway boasts some of the best wind resources in Europe. The combination of technological advances and renewable energy support schemes will translate to large amounts of new wind power installations in the coming years. The key statistics for 2015 are shown in Table 1 and Figure 1.**

## 2.0 National Objectives and Progress

### 2.1 National targets

Renewable sources of electricity accounted to 97.6% of the national electricity production in Norway in 2015 and 1.7% of the electricity production came from wind power. With electricity consumption in the country totaling 130.4 TWh for the year, this meant a net electricity export of 14.6 TWh.

The already-high ratio of renewable energy production combined with concerns about wind power development's local environmental impacts has provided fuel for considerable public debate on the topic of wind power development in Norway in recent years.

As a member of the European Economic Area (EEA), Norway was obliged to accept the EU's renewable energy directive in 2011. The target for renewable energy was set to 67.5% of total energy consumption. This target is to be met through a combination of energy efficiency measures and increased renewable energy production.

The incentive mechanism for increasing renewable energy production in Norway is a joint support scheme with Sweden to finance 26.4 TWh/yr of new renewable energy production by 2020. This market-based electricity certificate scheme is unique in that the targets are both country- and technology- neutral, meaning that the policy does not dictate which country the new renewable energy production comes from or which type of renewable energy is produced. Rather, the objective of this policy is to allow the market to dictate what type of renewable energy production comes and where, thus ensuring a cost-effective increase in renewable energy production when seen from a macroeconomic standpoint.

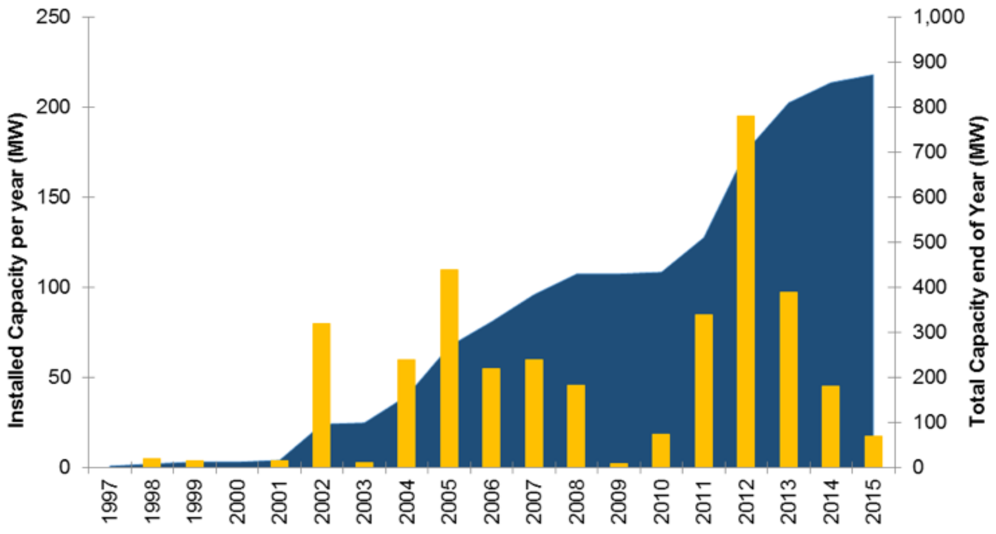


Figure 1. Installed wind capacity in Norway 1997–2015

In practice this means that Norway has no explicit wind energy target, however considerable new wind energy installations in Norway are regareded by analysts as implicitly necessary to reach the targets set forth for new renewable energy production through the joint agreement with Sweden.

### 2.2 Progress

Norway entered into the electricity certificate scheme with Sweden on 1 January 2012, and so far, the only large-scale Norwegian wind farms participating in the scheme are phase II of Midtfjellet wind farm and Raggovidda wind farm. An investment decision was announced in early 2016 for deployment of 1,000 MW of new wind power in central Norway in the coming years. In addition, a number of investment decisions are expected for smaller wind farms during 2016.

### 2.3 National incentive programs

Between 2001 and 2010, financial support for wind power projects in Norway was provided by the state-owned organization Enova SF on a case-by-case basis with the goal to support projects just enough to make them commercially viable. This program was terminated in 2011 and Norway and Sweden established a common electricity certificate market/scheme beginning January 2012. The economic incentive is designed to stimulate the combined development of 26.4 TWh/yr of new renewable power production in the countries. Since 2012, Enova has focused on supporting technology development connected to wind power.

A key aspect of the certificate system is that it shifts the cost for supporting renewables from Enova to the electricity consumer. Approved power plants will receive one certificate for every generated MWh from renewable energy sources. Hence, owners of approved plants have two products on the market: electricity and certificates which can be sold independently of each other. The demand for certificates is created by a requirement that all electricity users purchase certificates equivalent to a certain proportion of their electricity use, known as their quota obligation. The price of certificates is determined in the market by supply and demand, and varies from one transaction to another.

**Table 1. Key National Statistics 2015: Norway**

| | |
|---|---|
| Total (net) installed wind capacity | 873 MW |
| New wind capacity installed | 17.3 MW |
| Total electrical output from wind | 2.5 TWh |
| Average capacity factor | 34.7% |
| Wind-generated electricity as a % of national electric demand | 1.9% |

All renewables are included in the certificate system; it is technology neutral. All technologies receive the same number of certificates per MWh, and there are no specific quotas for wind power. Nevertheless it is expected that these electricity certificates will primarily stimulate new production from wind- and hydropower in Norway and bioenergy and wind power in Sweden, since other renewables (e.g., power from ocean energy and solar energy) are still considerably more costly.

## 3.0 Implementation

### 3.1 Economic impact

The Norwegian industry takes part in component production for wind energy systems (e.g., wind turbine blades and nacelles) on a relatively small scale. Companies with experience from the offshore oil industry, such as OWEC Tower and Aker Solutions, have widened their scope of interest and engagement to the offshore wind industry. These companies offer offshore wind turbine substructure solutions like jacket quatropods and tripods. Increased construction of wind farms will generate engineering and construction jobs, and ultimately jobs for maintenance personnel.

### 3.2 Industry status

Production of wind power is dispersed among several energy companies, some of which are small local utilities. The largest wind power projects are operated by large national energy companies. Some Norwegian companies (Fred Olsen Renewables, Statkraft, and Statoil) are also engaged in projects in foreign countries, like offshore wind in the United Kingdom. So far, there is no significant wind turbine manufacturing industry in Norway.

### 3.3 Operational details

In 2015, the capacity factor of wind farms in normal operation varied between 6% and 50%. The generation weighted average capacity factor was 35% for wind farms in normal operation for the whole year. The technical availability of new wind turbines in Norway is usually in the range of 95% to 99%. Annual energy per swept area ranged from 235–1,883 kWh/m$^2$, with a national average of 1,355 kWh/m$^2$.

### 3.4 Wind energy costs

The total wind farm installation costs reported in 2014 and 2015 averaged approximately 12 million NOK/MW (1.3 million EUR/MW; 1.4 million USD/MW). Annual maintenance is estimated to be between 0.10 and 0.15 NOK/kWh (0.010–0.016 EUR/kWh; 0.011–0.017 USD/kWh. Estimates of production costs for projects realized in 2014 and 2015 (38% average capacity factor) suggest a production cost of about 440 NOK/MWh (46 EUR/MWh; 50 USD/MWh) including capital costs (discount rate 6%, 20-year period), and estimated operations and maintenance costs of 0.125 NOK/kWh (0.013 EUR/kWh; 0.014 USD/kWh).

## 4.0 R, D & D Activities

### 4.1 National R, D & D efforts

In Norway there are two research centers for offshore wind energy, the Research Center for Offshore Wind Technology (NOWITECH) at SINTEF Energy Research, and the Norwegian Center for Offshore Wind Energy (NORCOWE) at Christian Michelsen Research. Another center, the Center for Environmental Design of Renewable Energy (CEDREN) conducts research on environmental issues within wind energy and other renewable energy production. These centers receive half of their funding from the Research Council of Norway; the remainder is jointly funded by industry and the research institutions.

The Research Council of Norway also administers a public research program for sustainable energy, ENERGIX. This program covers renewable energy, energy efficiency, energy systems, and sustainable transport (hydrogen, fuel cells, biofuels, and batteries). Industry, research institutes, and universities may receive funding for their research through proposals to regular calls. The budget for 2015 was 400 million NOK (42 million EUR; 45 million USD). In total, the Research Council granted 90 million NOK (9.4 million EUR; 10.2 million USD) to wind energy research in 2015.

In December 2015 the following wind energy R&D projects were approved for funding:

- Innovative Mooring Systems, DR TECHN Olav Olsen AS
- OO Installer—Installation Tool for Offshore Wind Turbines, DR TECHN Olav Olsen AS
- Second generation Seatower CFG-foundation, Seatower AS
- Nowcasting for wind energy production, Kjeller Vindteknikk AS

In total 14 R&D projects are funded by ENERGIX with 20 industrial companies and five research institutes are involved in these projects.

The Norwegian energy agency, Enova, offers capital grants for full-scale demonstration projects for ocean renewable energy production including offshore wind. While up to 50% of eligible costs can be covered, Enova's funding measured in absolute figures is limited. Innovation Norway runs a program supporting prototypes within environmental friendly technology andwind energy is included in this definition. Projects are supported with up to 45% of eligible costs.

### 4.2 Collaborative research

In 2015, Norway participated in the following IEA Wind Technology Collaboration Programme (TCP) Tasks: Task 11 Base Technology Information Exchange; Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power; Task 26 Cost of Wind Energy; Task 29 Mexnext: Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models; Task 30 Offshore Code Comparison Collaboration Continuation with Correlation (OC5); Task 31 WAKEBENCH: Benchmarking Wind Farm Flow Models, Task 32 LIDAR: Lidar Systems for Wind Energy Deployment, Task 33 Reliability Data: Standardization of Data Collection for Wind Turbine Reliability and Maintenance Analyses, Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN), Task 36 Forecasting for Wind Energy, and Task 37 Wind Energy Systems Engineering: Integrated Research, Design, and Development.

## 5.0 The Next Term

The next term will be dominated by the impetus given to the wind power industry by the electricity certificate scheme. This scheme has also contributed to a trend toward to the development of wind farms in Norway by large international companies.

**References:**

Opening photo: Raggovidda Wind Farm (Source: NVE)

Authors: Harald Rikheim, Norwegian Research Council and David E. Weir, Norwegian Water Resources and Energy Directorate, Norway.

# 35 Portugal

## 1.0 Overview

**In 2015, the wind energy sector achieved maturity within the Portuguese power system. While some capacity was added (80 MW), after 15 years of intense deployment Portugal reached 5,033 MW of installed wind power capacity by the end of 2015. This represents 26% of the total operational capacity and 41% of renewable energy capacity in the country (considering only mainland Portugal) [1, 2].**

**Portuguese wind parks produced 11.6 TWh, representing 23% of the annual electricity consumption in 2015. This wind penetration was influenced by the wind conditions observed in the winter months (January, February, and December) over the central and northern regions of mainland Portugal where the largest concentration of wind capacity is installed [1]. Despite a small reduction in the average yearly wind energy penetration, a historic instantaneous penetration was achieved with the wind production above the national consumption during several hours on 28 December 2015.**

**Electricity generation from renewable energy sources in 2015 reached 47% of the national consumption [1, 2]. However, 2015 was an extremely dry year, the sixth driest hydro year since 1931. Therefore, due to the reduced hydro participation, the renewable contribution to the energy mix decreased 18% in comparison with the previous year.**

**Due to the energy efficiency measures implemented in previous years and to economic stalling, electricity consumption in Portugal was 50.4 TWh in 2015, which corresponds to a slight increase of 0.1% with respect to 2014 [1, 2].**

**Figure 1 depicts the yearly contribution of each energy technology to the Portuguese energy mix, as well as the energy imports and the consumption index in the period 2008–2015. From Figure 1 it is possible to verify that the Portuguese's dependence on fossil fuels to balance the demand was following a downward trend that reached a lowest value of approximately 35% during 2014 and the trend reversed in 2015.The fossil fuel contribution was predominantly coal and natural gas in 2015.**

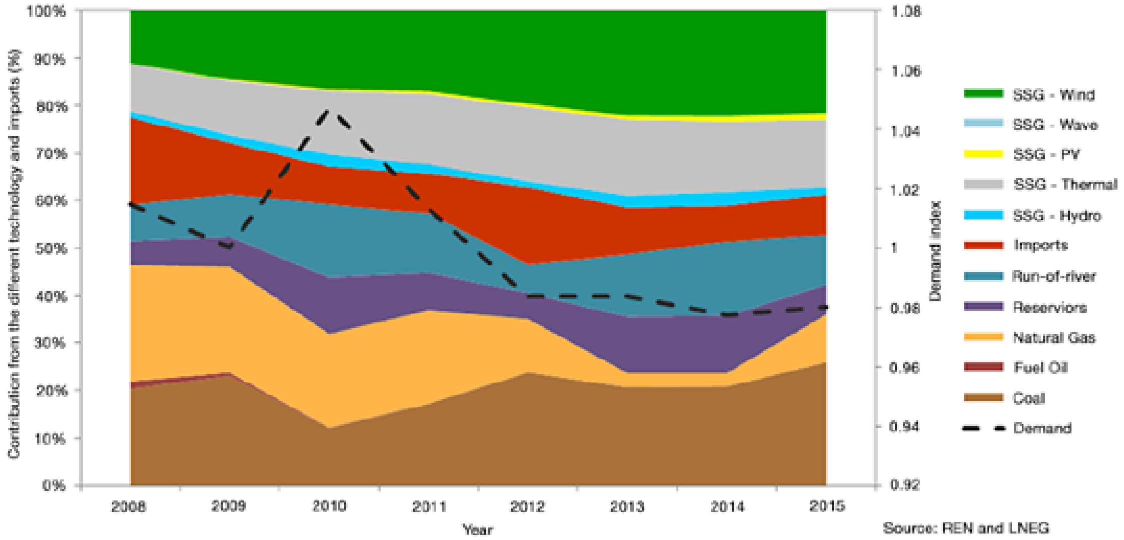
## 2.0 National Objectives and Progress

### 2.1 National targets

The targets for installed capacity currently in place were established in April 2013 by the Portuguese government through the National Renewable Energy Action Plan (NREAP) 2013–2020 [3]. Regarding wind power, this action plan sets the capacity goal of 5,300 MW by 2020. This value is divided into 5,273 MW land-based (including 400 MW to expand the capacity of current wind parks for "overcapacity") and 27 MW offshore.

### 2.2 Progress

During 2015, a net capacity of 80 MW was added and an accumulated capacity of 5,033 MW was achieved. Since the strong wind deployment initiated in 2004, following the favorable policies for renewable energies in Portugal, 2015 had the lowest installed capacity—translating to the maturity of the wind sector as well as nearly achieving national targets. Additionally, no new wind power capacity was installed during 2015 in the archipelagos of Azores and Madeira [1]. Cumulative installed capacity in 2015 is distributed over 245 wind farms and 2,590 wind turbines operating across the country (mainland and islands), including a floating offshore wind turbine with 2 MW [4].



Source: REN and LNEG

Figure 1. Yearly contribution from each technology for the energy consumption, imports and exports, and demand index for the period between 2008 and 2015 (mainland only) [2]

The Portuguese wind power fleet in 2015 generated 11.6 TWh corresponding to 23% of the electricity demand. The wind share of the total renewable production was 45.7%. In 2015, wind energy exceeded hydro energy in Portugal for the first time (38.6% of the total renewable production). This enhances the complementary role of the different renewable energies and reinforces the role of wind as a strong contributor for the Portuguese power system security of supply on an annual basis. The remaining mix of renewable sources maintained their shares with the biomass sector representing 9.4%, followed by PV (3.0%), and geothermal (0.8%) [2].

In 2015, the average national production at full capacity stood at 2,310 hours, which corresponds to a 6% decrease with respect to the same period in 2014 (2,440 hours). This result is mainly explained by the small reduction of the wind energy index.

### 2.3 National incentive programs

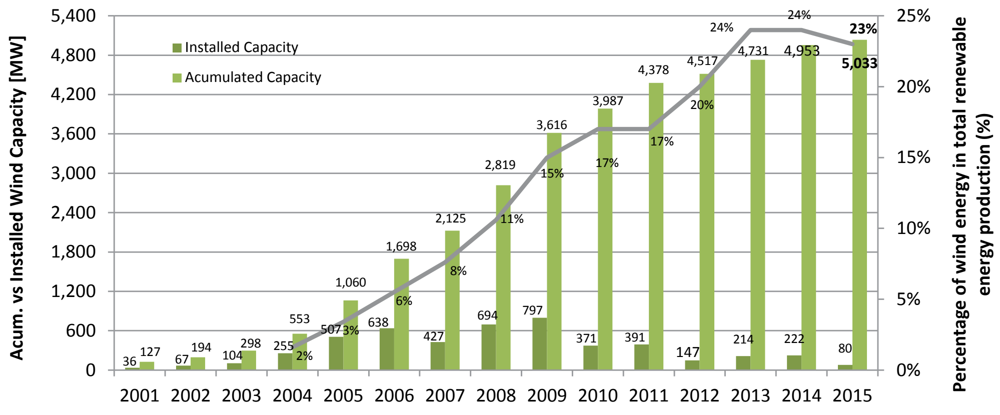
Since 2013 the NREAP remains unchanged and therefore the renewable targets previously set to 2020 are active and established as a 10.0% contribution for the transportation sector, 35.9% in heating and cooling sectors, and 59.6% in electricity [3].

A new Decree-Law, 202/2015 was published on 13 July for the offshore wind sector [5]. This new law creates a guaranteed remuneration base scheme of 80 EUR/MWh (87 USD/MWh) for new plants and allows wind power plants that are in a pre-commercial or experimental phases to benefit from the EC NER 300 funding program and or the Carbon Portuguese Foundation, in which case the remuneration scheme may add an additional value of 20 EUR/MWh (22 USD/MWh). For projects where the Portuguese authorities recognize a high added value for the country, the base remuneration can be multiplied by a factor (*k*) up to 5.25. The value of this factor is to be issued by the government using

**Table 1. Key National Statistics 2015: Portugal**

| | |
|---|---|
| Total (net) installed wind capacity | 5,033 MW |
| New wind capacity installed | 80 MW |
| Total electrical output from wind | 11.6 TWh |
| Wind-generated electricity as a % of national electric demand | 23% |
| Average capacity factor | 27% |
| Target: | Land-based: 5,273 MW<br>Offshore: 27 MW by 2020 |

# 35 Portugal



Source: DGEG , REN and LNEG

Figure 2. Installed versus accumulated wind capacity (bar graph) and percentage of wind energy production (line graph)

specific legislation to be published for each project on case by case basis.

During 2015 a new legal framework for *overcapacity* of wind parks, Decree-Law 102/2015, was released to amend the previous Decree-Law 94/2014 [5, 6]. In this new legal context, the additional energy is defined as the active energy obtained using the *additional capacity*, which corresponds to the maximum additional power taking into consideration the difference between installed capacity and maximum grid connection power. It is important to note that the energy generated under this legislation can only be injected to the local electrical grid after all legal, technical, and safety conditions are met.

National incentives for micro- and mini-wind generation were maintained and regulated by the Decree Law 153/2014 in 2015 [7]. Similar to 2014, the actual feed-in tariffs (FITs) remained valid for the existing installations during the statutory period.

### 2.4 Issues affecting growth

In 2012, the Portuguese government suspended the attribution of new capacity for grid connection to re-evaluate the legal framework for electricity generation [8]. The deployment of land-based wind projects during 2015 corresponds to the installation of the wind capacity licensed until 2012 and to *wind park additional capacity* ("overcapacity") granted under DL 94/2014 and 102/2015.

For several years, Portugal maintains the second highest yearly wind contribution for the energy consumption in the world, only surpassed by Denmark. It is a country that together with Spain operates in a "near electric island" power system due to its extreme western position in Europe and the weak electrical interconnection between Spain and France.

The existing high wind energy penetration has not introduced any evident negative impacts in the Portuguese power system's operation. However, operation of the power system under very high wind penetration (typically above 80% of the consumption) raises technical challenges that require a high level of know-how and expertise both from the wind park developers and the power system operator. This suggests a more conservative approach for the deployment of variable renewables in the near future, especially when not correlated with demand.

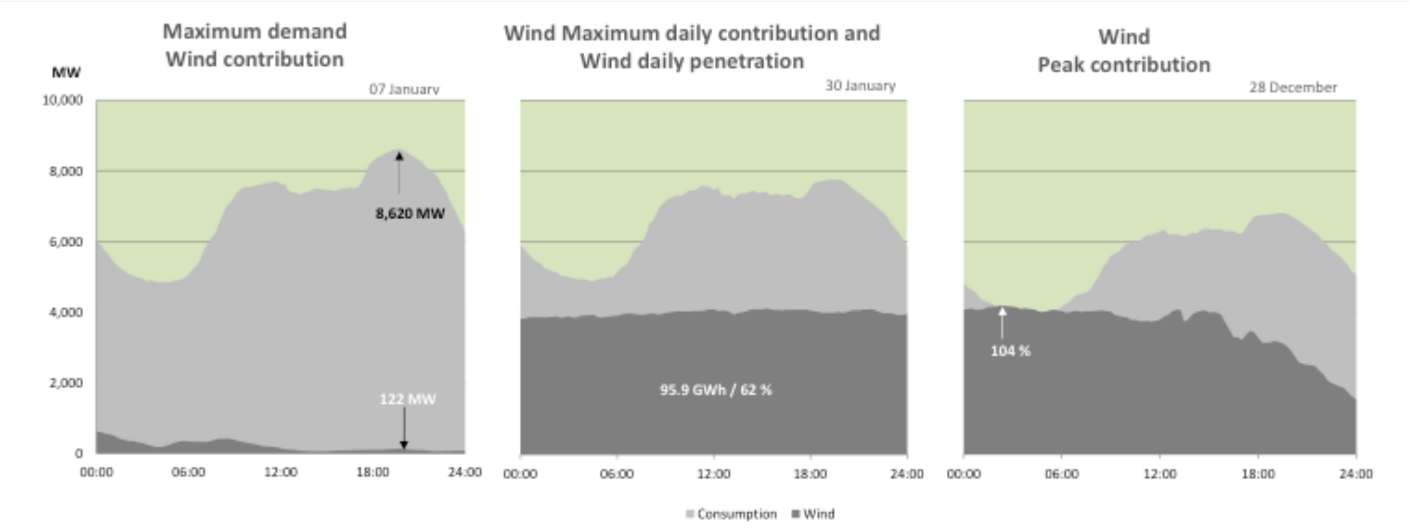


Figure 3. Extreme (high and low) wind power penetration and energy generation during 2015 [2]

Portugal has installed and is operating a very high share of power production with a stochastic and non-dispatchable behavior such as wind power, run-of-river hydropower plants, and also some PV plants. In light of the current power system's operation principles, this requires a certain amount of dispatchable sources in order to guarantee the balance between the electric generation and demand. In power systems such as the Portuguese, the design parameter limit is usually the extreme penetration of renewable, non-dispatchable sources.

The annual peak demand instantaneous value occurred on 7 January 2015 at 19:45 and had a wind power of only 122.5 MW (2% of the wind power capacity). On 28 December 2015 from 02:00 AM until 05:30, the wind power penetration was above the national consumption, and the highest instantaneous penetration of 1.04% from wind generation was recorded at 04:15 AM with a generation of 4,121 MW from wind. The highest daily consumption supplied by wind energy generation occurred on 30 January 2015 with 95.9 GWh, which accounted for 62% of the daily demand [2].

Despite the extremely high wind penetration values recorded in 2015, no technical problems were reported during these occurrences by the Portuguese transmission system operator (TSO) Redes Energéticas Nacionais, S.A. (REN). Figure 3 depicts the wind generation profiles on: (i) the maximum demand day and the respective wind power contribution; (ii) maximum daily contribution from the wind and the daily wind penetration; and (iii) peak wind penetration.

## 3.0 Implementation

### 3.1 Economic impact

The wind industry in Portugal, together with the wind deployment activity (80 MW) and the O&M activity, supported an estimated 3,251 direct jobs. According to the Portuguese Association of Renewable Energy (APREN), the sector generates 4.6 total jobs per MW, thus the estimated number of direct and indirect jobs in the wind sector is 23,152. In 2015, wind generated electricity produced an estimated income of 1,113 million EUR (1,211 million USD) and allowed savings of 4.1 million tons of CO$_2$ emissions.

### 3.2 Industry status

Since few wind turbines are currently being installed in the country, the majority of the production capacity of the Portuguese industrial facilities is now being exported with a positive effect on the national balance of trade.

During 2015, Enercon reinforced its leading position in Portugal as the largest supplier of installed capacity. The majority of wind turbines installed in 2015 are Enercon wind turbine models (Enercon E82 and E92 models) and the remaining wind turbines were manufactured by Senvion. As a consequence, Enercon increased its share in the Portuguese market to 56.0% of the installed wind capacity, followed by Vestas with a 13.3% share, Gamesa (9.8%), Nordex (8.2%), Senvion, formerly REpower (4.3%), GEWE (2.1%), Ecotècnia (2.1%), Suzlon (2.0%), Bonus (1.5%), and other manufacturers (0.6%), as shown in Figure 4 [4].

From the new wind turbines installed in 2015, 14% was for wind park capacity reinforcement—usually referred as *overcapacity*, a wind plant design principle that allows for installing more wind capacity than the maximum electric power allowed to be injected in the grid.

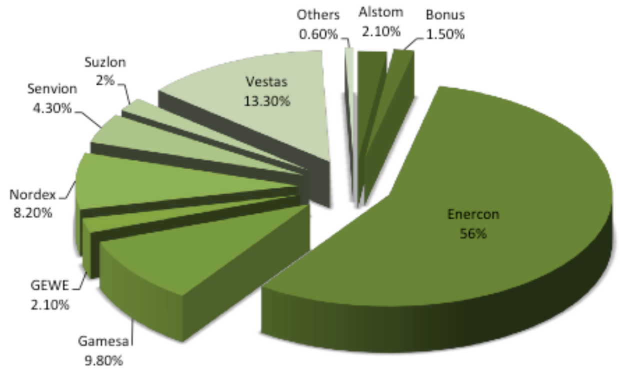


Figure 4. Distribution of installed wind capacity by manufacturer [4]

Concerning offshore wind systems, there are several initiatives to develop new innovative structures (both floating and sea bottom-fixed) to support offshore wind turbines. The demonstration of a new technology is being supported by the H2020 European project Demogravi3, led by EDP Renewables with participants including: ASM Energia (PT), Acciona Infraestructuras (ES), Fraunhofer IWES (DE), Técnica y Proyectos SA (ES), University Politécnica de Madrid (ES), Harbour Research (ES), WavEC (PT), Gavin & Doherty (IE,) and Global Maritime (NO).

The WindFloat prototype maintained its successful demonstration offshore Aguçadoura in 2015. This concept structure proved to be a technically viable solution for future floating deep offshore wind plants in open Atlantic sea conditions. Notably, the Windfloat system survived 16-m waves with only minor requirements for maintenance. During 2015, WindFloat reached another milestone; it passed the 14 GWh mark and by the end of 2015 had already delivered 14.6 GWh of wind electricity to the grid [9].

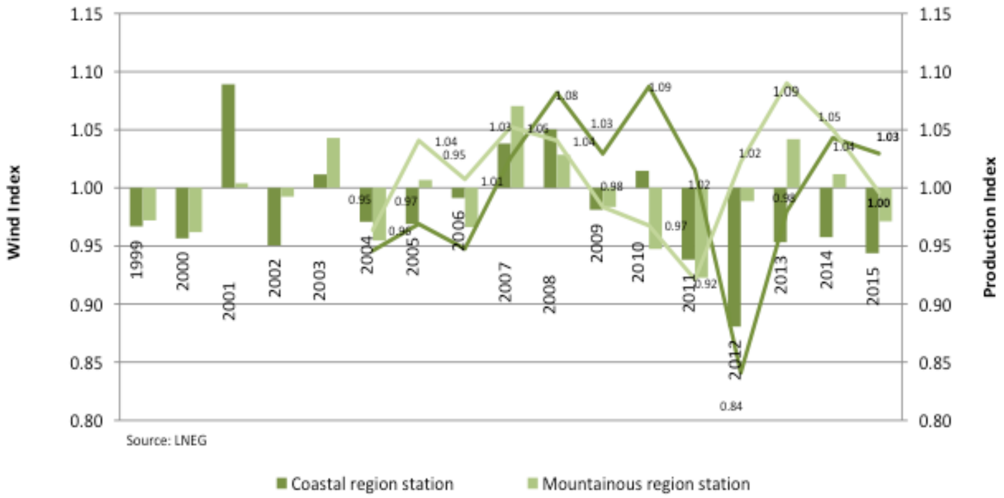
The performance achieved with this floating system has enabled the Portuguese consortium exploring the technology, Windplus led by EDP Renewables, to initiate the design of the first wind park with this floating technology to be installed off the Portuguese Coast with a 25-MW capacity. The wind park will be built of the coast of Viana Do Castelo with European EC NER300 co-funding. Offshore installation—foundation and turbines—are anticipated to start in 2018 [9].

### 3.3 Operational details

In mainland Portugal, six new wind parks were connected to the grid in 2015. The overall installed capacity of the 245 wind parks on the mainland through 2015 can be grouped into three categories; <10 MW, with a 52% share; 10–50 MW, with a 41% share, and >50 MW with a 7% share [4].

Figure 5 shows the wind and production indexes since 1999. These values were achieved for the two regions where wind turbines typically operate in Portugal: coastal and mountainous. The wind and production indexes were computed based on reference wind data from anemometric stations installed in these two regions. After two years of high values in the mountainous regions, LNEG indexes for wind and power production show a decrease of the wind index of 3% below the average (0.97). In the coastal regions the wind index was 0.94 in 2015.

Data from the operation of power systems for 2015 indicates a decrease of 10% in the total annual wind generation index to 1.01 when compared to the previous year [2]. This result reveals the expected



Source: LNEG

Figure 5. Wind (bar graph) and production indexes (line graph) on coastal and mountainous regions of Portugal

similarity to the typical mountains behavior, since the vast majority of the operating capacity in Portugal is installed in that region.

### 3.4 Wind energy costs

The average cost per MW installed in 2015 was approximately 1.35 million EUR (1.47 million USD). This value includes associated costs of project installation and grid connection, among other direct costs. Turbine costs were around 80% of the total installation costs and corresponded to approximately 1.08 million EUR/MW (1.18 million USD/MW).

The mean tariff paid to the wind power plants in 2015 was 94.24 EUR/MWh (102.62 USD/MWh). Portuguese legislation published in 1990 assumes a period of 12 to 15 years during which a guaranteed green FIT applies to the retribution of wind generation. In special contracts with reduced FIT tariffs (approximately 70 EUR/MWh; 76 USD/MWh) this period may extend up to 20 years. Since the bulk of wind deployment in Portugal started in 2003/2004, a large number of wind power plants are currently reaching the contractual maximum period of FIT retribution. Therefore, in the near future there will be a reduction in the wind energy mean tariff in Portugal.

## 4.0 R, D&D Activities

### 4.1 National R, D&D efforts

National R&D efforts during 2015 were mainly focused on offshore wind energy and development of tools and methodologies to maximize the penetration of renewable energy, both from a grid security operation point of view and also from a market perspective. These activities are taking place at the main Portuguese institutes and universities and being financed through national or European programs. Some relevant R&D activities undergoing in Portugal are:

- Project IRPWind: European-wide Measures and Structures for a Large-scale Wind Energy Integration: an FP7 European-funded project with the participation of LNEG. This project combines wind energy research projects and activities with the objective of fostering innovation, collaboration, and knowledge transfer between European researchers and leading R&D entities, with the participation of European energy Research Alliance (EERA) Joint Programme on Wind Energy partners.
- Project Keep-on-Track: a funded EC IEE project that aims for monitoring and publishing up-to-date market data and policy recommendations alongside the trajectory outlined in the RES Directive. The Portuguese Renewable Energy Association (APREN) is the Portuguese member for the project.
- Project OPTIMUS: a project that deals with demonstration of methods and tools for the optimization of operational reliability of large-scale industrial wind turbines. This project is funded by the EC FP7 program and the Portuguese industrial partner Instituto de Soldadura e Qualidade is the participating member.
- Project AEOLUS4FUTURE: a project that aims for the efficient harvesting of the wind energy. This project is funded under the EC FP7 H2020 program and the main goal of this project is to develop a sustainable Wind Energy Systems for a variety of EU needs. The University of Coimbra is the Portuguese member in this project.
- Project DREAM-GO: an international project that aims to contribute to a more sustainable and efficient energy system based on intensive use of renewable energy and active management of consumers. This H2020 project is led by the GECAD group that belongs to Institute of Engineering—Polytechnic of Porto (ISEP/IPP).
- Project ESFRI WindScanner: the project intends to establish a European network of innovative R&D for the acquisition of three-dimensional com¬ponents of the atmospheric flow and characterization of wind turbulence. It is funded by EC FP7 and has the participation of the Portuguese entities LNEG and Porto University.
- Project OceanNET: an international project concerning floating offshore wind and wave energy funded from the PEOPLE Programme (Marie Curie Actions) of the EC FP7. The main goal of this project is to educate a new generation of engineers and scientists in the area of floating offshore wind and wave renewable energies to support the emerging offshore renewable energy sector. This proj¬ect has the Portuguese participation of WavEC and Instituto Superior Técnico.
- Project LEANWIND: an international project concerning the effectiveness and efficiency of the offshore wind farm lifecycle and supply funded by EC FP7. The main goal of this project is to develop innovate technical solutions and processes to optimize offshore wind park deployment, operation, and maintenance as well as decommissioning procedures. This project has the Portuguese participation of EDP Inovação.
- Project DEMOGRAVIT3: an international project concerned with offshore wind energy funded by the EC FP7 H2020 program. The main goal of this project is the development of a new innovated gravity foundation to support offshore wind turbines. This project is led by the Portuguese EDP company.
- Project NEWA: an international project concerning wind atlas for land-based and offshore European countries, funded by the EC FP7 ERA-NEP Plus program. The main goal of this project is the creation and publication of a new European Wind Atlas based on improved modeling competences on atmospheric flow and its interactions over terrain and sea-surface areas. It will account for interactions of wind turbines and wind farms over all EU Member States and some associated countries. This project has the Portuguese participation of FEUP, LNEG, IPMA, and INEGI.
- Project RICORE: an international project aiming to establish a risk-based approach to approving novel technology of offshore renewable energy systems on its environmental sensitivity in the site where it will be deployed. This project is funded by the EC PF7 H2020 and has the Portuguese entity Wavec as a project member.
- Project EERA.DTOC: an international project concerning a design tool for an offshore wind farm cluster, funded by the EC FP7 program. This project closed in June 2015 and the main goal was to combine gained expertise in a common integrated software tool for the optimized design of offshore wind farms and wind farm clusters acting as wind power plants. The project had the Portuguese participation of Porto University.

### 4.2 Collaborative research

In Portugal, LNEG and other Portuguese R&D entities are active partners in international research efforts. The country participates in IEA Wind Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power. Portugal also collaborates in the IEA Wind Task 36 Forecasting for Wind Energy. In addition to the IEA Wind activities, LNEG is the Portuguese representative in the European Energy Research Alliance Wind Program (EERA-Wind) which is a European initiative that integrates the leading European research institutes in the energy sector and aims to strengthen, expand, and optimize EU wind energy research capabilities. The Portuguese participation in this task is coordinated by INESC-TEC and also involves LNEG, Prewind, and Smartwatt.

## 5.0 The Next Term

Portugal is reaching the official targets for onshore wind capacity with few pending licensing procedures. The wind penetration in the country is already close to reaching a one quarter of the electric consumption—one of the highest in the world. Therefore, 2017 is expected to be a stagnant year regarding the installation of new wind capacity. Alternatively, Portugal is now starting the offshore wind energy deployment through the new project, Windfloat Atlantic, that will deploy the first floating offshore wind park off the Portuguese coast near Viana do Castelo with an estimated capacity of 25 MW.

**References:**

Opening photo: EDP Renewables Windfloat's semi-submersible floating foundation installed off the Portuguese coast, close to Aguçadoura

[1] *Renováveis – estatísticas rápidas Janeiro 2016*, technical report 135, Direcção Geral de Energia e Geologia (DGEG), 2016. www.dgeg.pt

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Authors: Ana Estanqueiro, Paulo Costa, António Couto, and Teresa Simões, Laboratório Nacional de Energia e Geologia (LNEG), Portugal.

# 36 Spain

## 1.0 Overview

The Spanish Wind Energy Association's (AEE) reported the installed wind capacity in Spain was 22,988 MW in 2015 with no new wind power capacity added in 2015. According to the national transmission systems operator (TSO) Red Eléctrica Española (REE), Spanish electrical energy demand increased to 244.99 TWh, up 1% from 2014. Wind energy produced 47.70 TWh of electricity, equal to 19.4% of the yearly energy electricity demand and was the third largest source of electricity in the Spanish power system (Figure 1). In February 2015 wind generation was the main source of generation.

During 2015, no new wind turbines were installed in Spain. This has not happened since the beginning of wind energy development in the 1980s. The pause in the wind energy market is due to the energy reform enacted in 2012.

Despite the 1% power demand increase in 2015, the total installed capacity is nearly twice the current peak demand. The target agreed with the European Union to reach at least 20% of total energy consumption from renewable energy sources by 2020 forced the government to publish the "National Planning of Electric Transportation Network 2015–2020" strategy, which includes 6,400 MW of new wind capacity [1].

Based on this strategy, during 2015 the government approved a call to allocate 500 MW of new wind energy capacity using an auction. In this descending auction, the government established investment retribution to developers in 2015 based on a total capital expense (capex) of the installation of 63,243 EUR/MW (68,808 USD/MW). Generally, bidders have to present reductions of total capex under the standard capex value considered by the government—1.2 million EUR/MW (1.3 million USD). This standard capex value has been estimated based on a reference installation type with a profitability of 7.4%, 2,800 equivalent hours/year, 20-year expected lifetime, and operating expense (opex) of 24.95 EUR/MWh (27.14 USD/MWh) for the first year. In the auction, some wind capacity is offered to bidders without any site identification.

Finally, in 2015 the government also published a new law which established the technical and economic conditions of the modes of supply of electric power with self-consumption.

## 2.0 National Objectives and Progress

### 2.1 National targets

On 11 November 2011, the new Renewable Energy Plan (REP 2011–2020) [2] was approved by the Spanish government for the years 2011 to 2020, establishing the development framework for the renewable energy sector. This plan aimed to fulfill and go beyond the EU objectives of covering 20% of total energy consumption by renewable sources by 2020. The REP 2011–2020 established Spanish objectives and suggested the measures to be implemented to reach the 20% goal. It included the Spanish vision for each type of renewable energy. The public entity in charge of implementing the REP 2011–2020 was the Institute for Energy Diversification and Savings (IDAE).

For wind energy, the objective for 2020 was 35,000 MW. Offshore wind power is still in the early stages of development, with R&D projects being carried out. By the end of the REP 2011–2020, it was estimated that wind energy would continue to be the largest renewable energy contributor with 35,000 MW (71,540 GWh/yr) land-based and 750 MW (1,845 GWh/yr) offshore. From 2011 to 2015, only 2,360.5 MW of new wind capacity has been installed, so it seems difficult to meet the EU objectives by 2020.

According to the new energy planning exercise published by the Ministry of Industry, Energy and Tourism in 2015 [1] renewable energy sources should satisfy 36.6% of gross energy generation with an increase of capacity based mainly on the current most competitive technologies: wind and solar PV energy). In this way, the capacity forecast for wind is 25,579 MW by 2016 and 29,479 MW by the end of 2020. That means 6,473 MW over the cumulative wind capacity in 2013 (23,000 MW).

Taking into account that no new wind capacity has been installed in 2015, it seems unlikely that the European 2020 target for renewable energy sources can be met. In 2016 alone, 2,500 MW would have to be installed. This would be a return to growth rates prior to the Reform, but with much more restrictive conditions. At least, the Executive has convened the terms of the auctions that are required according to the new regulation to install new power.

### 2.2 Progress

According to the Spanish TSO REE, the electrical generation capacity in the Spanish mainland system remained nearly constant in relation to 2014. At the end of 2015 a total of 102,613 MW of generation was operational, 354 MW or 0.3% higher than 2014 [3]. The changes in technologies included a reduction in power by 520 MW due to the dismantling of a fuel/gas plant. Capacity was increased by 854 MW of hydro and 20 MW of solar PV.

Good results were achieved by installing the 12-MW Wind-Hydro System in the Hierro Island (Canary Islands). In 2015, the system has avoided burning 3,284 tons of fuel, avoided the emission of 10,800 tons of $CO_2$, and produced 8,503 MWh of electricity.

In Spain, the use of wind power has lowered carbon emissions by about 24.34 million tons during 2015. Regarding $CO_2$ emissions from the peninsular electricity generation sector, they increased by 20% from 60.4 million tonnes in 2014 to 73.0 million tonnes in 2015, due to the increase in production from coal-fired power stations. These emissions were mitigated only partially by the generation based on renewable energy sources. Hydro and wind power generation was reduced in 2015 due to lower rainfall and wind resources. Nationwide, wind generation has saved up to 9.51 million tons of conventional fuels and has supplied the electrical consumption of more than 15.39 million Spanish households.

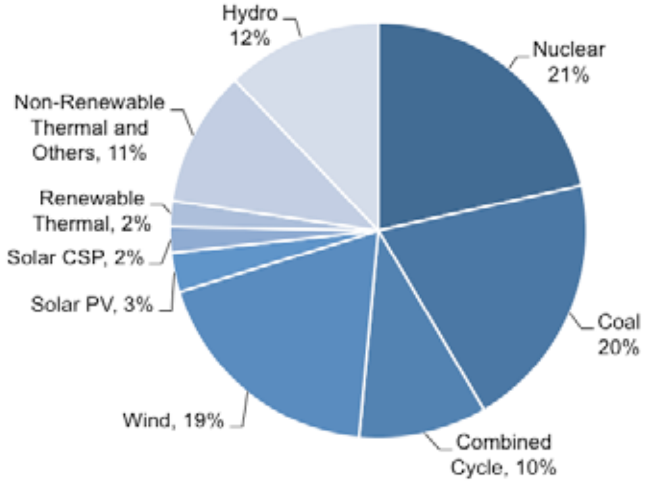

Figure 1. Percentages of the 2015 power supply mix in Spain (Source: REE)

### 2.3 National incentive programs

Currently, auctions are used to promote renewable energies. The previous FIT-based support scheme was abandoned in 2012. Before the moratorium of 2012, there were around 10,000 MW of wind power in Spain that had been awarded incentives through the years in different regional competitions but were never installed due to the forced paralysis of the sector. Some of these projects can bid in the different calls for auctions that will be programmed from 2016 to 2020.

In order to comply with Spain's 2020 Energy Planning and meet the EU's 2020 goals in terms of energy consumption, 6,400 MW of new wind energy capacity has to be installed [1]. In this way, by the end of 2015 only a 500-MW auction has been programmed for 2016.

### 2.4 Issues affecting growth

The energy reform has been the main cause of the slowdown in wind development. It has generated legal uncertainty by the retroactive modification of the regulatory framework and by the adoption of a new payment system. The new system allows changing the economic conditions for payment every six years without informing the industry beforehand about the methodology to be used. As a result, wind turbine production in Spain is declining. Over the past six years, the wind power sector has reduced the employment by more than half. In 2014 (there are no data available for 2015 yet) the wind power sector employed 16,753 people. In 2013, 1,097 jobs were lost. In 2014 the wind power sector generated 60% less employment than in 2008, when the number of people employed in the sector was 41,438 [5].

## 3.0 Implementation

### 3.1 Economic impact

Given the regulatory situation in Spain, no wind capacity was installed during 2015, so total capacity remains at 22,986.5 MW. Operating wind plants cover 19.4% of the Spanish electrical demand. This implies a huge accomplishment by the developers

**Table 1. Key National Statistics 2015: Spain**

| | |
|---|---|
| Total (net) installed wind capacity | 22,988 MW |
| New wind capacity installed | 0 MW |
| Total electrical output from wind | 47.7 TWh |
| Wind-generated electricity as a % of national electric demand | 19.4% |
| Average capacity factor | 23.9% |
| Target 1. Official Electric Transport Network Planning 2015–2020 | 29,388 MW |

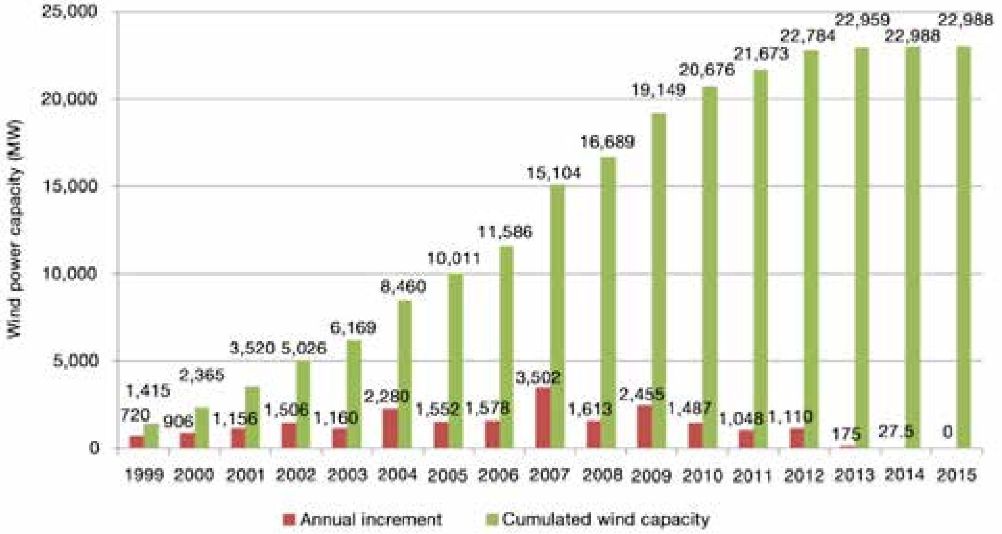

Figure 2. Annual and cumulative installed wind capacity in Spain

and manufacturers. In 2014 (there are no data available for 2015 yet) the wind power sector contributed 1,526 million EUR (1,660 million USD) to GDP, 47.3 % fall compared to the 2012 contribution, of 2,898 million EUR (3,153 million USD [5].

### 3.2 Industry status

Most of the main wind power manufacturers in the world are present in the Spanish market, but only activity for exportation from Spain was developed during 2015.

Gamesa is still the top manufacturer in Spain with 12,008 MW total wind capacity installed (52.3% of the total wind capacity installed). In the second position is Vestas Wind Power with 4,090.99 MW total wind capacity installed (17.8% of the total wind capacity installed), and Alstom Wind in third place with 1,739 MW (7.6% of the total wind capacity installed). The Spanish manufacturer Acciona Windpower is in the fourth position with 1,728 MW (7.5% of the total wind capacity installed).

Gamesa ended 2015 with 170 million EUR (185 million USD) net profit, 85% more than in 2014 (92 million EUR; 100 million USD). Gamesa's revenues totalled 3.504 billion EUR (3.812 billion USD) in 2015, 23% more than in 2014. This was the result of expanding revenues in its two business areas: wind turbine generators (+26%) and operation and maintenance services (+8%). As a result of growing demand, the volume of activity increased by 21% to 3,180 MW. By regions, India and Latin America continue to lead sales of wind turbines (in MW), representing 29% and 27%, respectively. Europe and the rest of the world contributed 18%, while China and the United States contributed 13% and 11%, respectively.

Also, in 2014, Areva and Gamesa created a joint venture company named Adwen. This joint-venture is responsible for the design, manufacturing, installation, commissioning, and services of offshore wind turbines. The first target of this new company is the design and development of a new 8-MW rated power wind turbine. Combining both Gamesa and Areva wind expertise and extensive track-record, Adwen is ideally positioned to become a leading player in the offshore wind segment, with a 2.8-GW project pipeline and the objective of garnering a market share of close to 20% in Europe by 2020.

The second Spain-based manufacturer Acciona Windpower (AWP) has signed an agreement to merge with the German wind turbine manufacturer Nordex in order to create a new wind energy industry leader. The transaction was based on cash and shares. The exchange amounts to 785 million EUR (854 million USD). The integration of AWP into Nordex will create a new, globally-positioned European powerhouse in the wind industry with manufacturing facilities in Germany, Spain, Brazil, the United States, and soon India. The two companies generated combined sales of 3.4 billion EUR (3.7 billion USD) in 2015 and have 4,800 employees.

Acciona reported a net profit of 207 million EUR (225 million USD) in 2015, 12.1% higher than that achieved in 2014. This was largely due to the growth of renewable generation activity in international markets and the good performance of wind turbine manufacturer, AWP. These results reflect the increase in international generation, driven by the installation of 123 MW (93 MW in South Africa, 30 MW in Poland) during 2015; as well as the growth shown by AWP, which reached 84 million EUR (94 million USD) compared to 39 million EUR (42 million USD) in 2014.

Several manufacturers are developing small wind turbines from 3 kW to 100 kW for grid-connected applications. Ennera, Sonkyo Energy, and Norvento are well positioned in foreign countries.

Regarding developers, no new wind energy capacity was installed in 2015, so the same figures reported in 2014 remain: Iberdrola Renovables with 5,513 MW operating represents 24.0% of the Spanish wind market; Acciona Energy with 4,268 MW represents 18.6%; the Portuguese company EDPR with 2,099 MW represents 9.1%; and the Italian utility Enel Green Power Spain with a total capacity installed of 1,403 MW represents 6.5%. In fifth place is Gas Natural Fenosa GNF, with 982 MW and 4.3% of the market.

Under this discouraging situation almost all the Spanish companies that have not stopped activity have opted to enter international markets. The Spanish wind sector exported around 2 billion EUR (2.2 billion USD) worth of equipment and services in 2015, an amount similar to the previous year, according to provisional data from the Ministry of Economy and Competitiveness. Some of the world's largest Spanish developers like Iberdrola or Acciona Energy are working quite well abroad.

In 2015, Iberdrola installed 139 MW of land-based wind capacity (3 MW in the United Kingdom and 136 MW in Mexico), and at the beginning of 2016, 38 MW were under construction in the United Kingdom. In Brazil, 174 MW were awarded in two auction awards in June and November of 2014. In the offshore wind area, in the United Kingdom, Iberdrola continues with the development of the Wikinger offshore project, of up to 350 MW (70 wind turbines), in the Baltic Sea (Germany). During 2015, Spanish suppliers were active in this project: some of the foundations were built by Navantia and Windar, the electrical substation was built by Navantia and Adwen as the wind turbine supplier (AD5-135 wind turbine). Furthermore, Iberdrola is developing in the United Kingdom, the "East Anglia I, II, and III" project in the North Sea. In 2015, public consultations were completed. Following this, the Application for Consent was submitted in November 2015. This was accepted by the Planning Inspectorate in December 2015. In 2016, the project will work through the pre-examination phase. Overall, Iberdrola manages either directly or through investee companies about 14,180 MW, of which 194 MW are offshore wind.

Acciona Energy's total installed capacity increased 7,087 MW to 7,210 MW in 2015 (220 wind farms in 15 countries) by commissioning the 138-MW Gouda Wind Farm in South Africa.

Similarly, the main Spanish manufacturer Gamesa Corporación Tecnológica seems to be getting off the ground. Activity increased in 2015 to 3,180 MW—21.33% more than in 2014 (2,623 MW) due to the strong contribution by the Indian (29% sales in 2015) and Latin American markets (27% sales in 2015).The remaining markets were in the U.S. (11% sales in 2015) and China (13% sales in 2015with contributions from emerging markets, such as the Philippines, Turkey, Cyprus, and Sri Lanka. Growth in those markets was offset by the lower contribution to sales by Europe and the rest of the world.

### 3.3 Operational details

The total number of turbines is more than 20,266 units. The average size of the turbines installed is 1.1 MW.

Wind turbines operating in Spain show important seasonal behavior. Annual electricity generated by wind farms was more than 47,707 GWh in 2015. During 2015, equivalent hours at rated power were approximately 2,100 hours for all of the wind farms. This shows that 2015 was a medium wind resource year overall, compared to, for example, 2014 or 2013 when the equivalent hours were higher at 2,223 and 2,350 respectively.

Although 2015 was not a very windy year, resulting in a 5.5% drop in total wind production in relation to 2014, historical power peaks were exceeded on several days. For example, on 21 November 2015, 70.4% of the Spanish power demand was covered with wind generation, 2% higher than the last record set on 25 December 2013, when wind covered 68.4% of demand.

### 3.4 Wind energy costs

Wind turbines manufactured in Spain during 2015 have average equipment costs in the range of 708–1,011 EUR/kW (770–1,100 USD/kW) cost. The average installed costs are in the range between 1,112–1,314 EUR/kW (1,210–1,430 USD/kW).

## 4.0 R, D&D Activities

### 4.1 National R&D efforts

In 2015, the Spanish government continued the State Plan for Scientific and Technical Research and Innovation 2013–2016 following the Spanish Strategy for Science Technology and Innovation put in force in 2011 [4]. This Plan tries to align as much as possible the research and innovation lines with the lines defined in the European Strategic Energy Technology Plan SETPlan.

The structure of the action plan for 2015 is based on four state programs:

1. Promotion of talent and employability in research & development & innovation (R&D&I)
2. Promoting scientific and technical excellence
3. Encourage corporate leadership in R&D&I
4. R&D&I focused on the challenges of the society

The State R&D&I Programme was established to face the current challenges of society: to obtain safe, efficient, and clean energy. During 2015 one call for collaborative public and private proposals was deployed with seven projects granted. These seven projects are listed below:

- *Floating platform of concrete for deep waters wind power exploitation. (MENHIR Project)* is coordinated by the company Dragados S.A. with a total budget of 1,123,989 EUR (1,222,900 USD) and support amounts 1,009,055 EUR (1,097,852 USD) (grant and loan).
- *Lean maintenance for offshore floating structures* is coordinated by Ingeteam Service S.A. with a total budget of 684,091 EUR (744,291 USD) and support amounts 553,723 EUR (602,451 USD) (grant and loan).
- *Research and development of new efficient manufacturing routes of large wind clamps (offshore and land-based)* is coordinated by Forjas Iraeta Heavy Industry S. L. with a total budget of 1,425,538 EUR (1,550,685 USD) and support obtained amounts 997,317 EUR (1,085,081 USD) (grant and loan).
- *Development of a new generation of efficient and light wind towers based on advanced models for optimized structural calculation (WINDFIT)* is coordinated by Gonvarri Eolica S.L. with a total budget of 1,614,833 EUR (1,756,938 USD) and support amounts 870,310 EUR (946,897 USD) (grant and loan).
- *Cost reduction for offshore wind (ReCoEFF)* is coordinated by ESTEYCO S.A.P. with a total budget of 554,580 EUR (603,383 USD) and the support amounts 536,405 EUR (583,609 USD) (grant and loan).
- *Energy storage hybrid system for hybrid generation systems (SH2)* is coordinated by Gamesa Electric Power Systems S.L. with a total budget of 1,596,272 EUR (1,736,744 USD) and support amounts 1,008,726 EUR (1,097,494 USD) (grant and loan).
- Finally, the last project is *Development and implementation of a system to support and accelerate the marine renewable energy by combining and creating of new methodologies and technologies in test centers (TRL+)* coordinated by the entity named Biscay Marine Energy Platform S.A. with a total budget of 2,290,484 EUR (2,492,047 USD) and support amounts 1,394,324 EUR (1,517,025 USD) (grant and loan).

Another new instrument to support innovative projects led by private companies has been developed by the Center for the

Technological and Industrial Development (CDTI). This program named CIEN is focused to support projects considered strategic. The aim is to fund major industrial research and large size experimental and strategic developments. Under this program, one project has been funded in 2015. The project *New innovative technical solutions for platforms and associated evacuation and integration network of marine floating offshore wind farms* is coordinated by the company Nautilus Floating Solutions S.L. The project partnership consists of six companies (Cobra Industrias y Servicios S.A., Ormazabal Districución Primaria S. L., Esteyco Energia S.L., Ormazabal Cotradis Transformados S.L., Nuevas estrategias de mantenimiento S.L., and Vicinay Sestao S.L.).

Another instrument managed by the CDTI is the Program IDL "Innovation Direct Line." The objective of this instrument is to support projects in which there is some involvement, incorporation, and adaptation of new technologies. The idea is to co-fund the selected projects jointly with the Technology Fund.

Under this funding instrument three projects have been approved:

- *Reducing the cost of wind power: New structural solutions for the treatment of the ice on the surface of the blade* is coordinated by Gamesa Innovation and Technology S.L.
- *Development of power converter for mid voltage networks* is coordinated by Gamesa Electric Power Systems S.L.
- *Automatic optoelectronic yaw measurement system* is coordinated by Kintech Ingenieros S. L.

Another program run by the CDTI is the EEA Grant, established in 2014 but started in 2015.

- *Experimental demonstration and certification of offshore technology foundation with self-erecting telescopic tower* is coordinated by Esteyco Energía S. L.
- *100 kW wind turbine for distributed generation and own consumption* is coordinated by Argolabe Ingeniería S.L.
- *Development of optimum technical solutions for tensioned mooring systems for TLP platforms applicable to offshore wind* is coordinated by Iberdrola Ingeniería y Construcción S.A.
- *Development of a new generation of efficient wind turbines* is coordinated by Alston Renewables S.L.
- *Development of new generation of multi-megawatt gears* is coordinated by Gamesa Energy Transmission S.A.
- *Development of the new 5 MW wind turbine for onshore applications* is coordinated by Gamesa Innovation and Technology S.A.
- *Development of a new concrete precast foundation* is coordinated by Esteyco Energía S.L.
- *Development of a 5 kW vertical axis wind turbine for residential and industrial self-consumption* is coordinated by the company Casal Cardona Industrial S.L.
- *Research on CAES for Wind Energy Management* is coordinated by Iberdrola Ingenieria y Construcción S.A.
- *Research and development of new technology for floating offshore wind energy and mooring systems* is coordinated by Saitec S.A.
- *New concept of offshore floating platform for wind turbines* is coordinated by Cobra Instalaciones y Servicios S.A.
- *System for evaluation and development of wind repowering projects* is coordinated by Gestamp Hybrid Towers S.L.
- *Intelligent system for energy storage for wind energy integration and power quality improvement* is coordinated by Iberdrola Ingenieria y Construcción S.A with Gamesa Electric. Power Systems S.L. and Cegasa International S.A. as partners.
- *Advanced magnetic small wind turbine* is coordinated by Boreas Nuevas Tecnologías S.A.
- *Development of electrical solutions for braking systems of wind turbines oriented to simplification and safety reinforcing in maintenance* is coordinated by Ato Wind turbines S.L.
- *High accuracy measuring and correction system for blade pitch systems oriented to output power maximizing* is coordinated by Hispavista S.L.
- *URBWIND* is coordinated by Geolica Innovations S.L.
- And finally the project *Vortex Wind turbine* is coordinated by Vortex Bladeless S.L.

In conclusion, 28 relevant projects have been started in 2015 (nine projects dealing with offshore wind, seven focused on new wind turbine converters, eight addressing research in components, one in manufacturing processes, two in wind integration matters, and one in new wind energy markets), as shown in Figure 3. Table 2 shows main budget figures.

Another important initiative regarding research activities on wind energy is the Alliance for Energy Research and Innovation (ALINNE). ALINNE is a non-profit initiative that was created by the former Ministry of Science and Innovation (currently included in the Ministry of Economy and Competitiveness as a Secretary of State). CIEMAT is the leader to bring together and coordinate efforts among all actors in the value chain of R&D in energy (industry, R&D sector, and government). This coordination will allow response to the major challenges that the policy of R&D&I has in the energy sector, and will contribute to defining working guidelines at national and European level.

Finally, it is worth highlighting the important activity developed by Spanish research centers in the European Energy Research Alliance (EERA). The Spanish team coordinated by CENER with the participation of CIEMAT, CIRCE, CTC, IC3, IREC and TECNALIA is participating in most of the initiatives (EERA-DTOC, IRPWIND Project, NEWA ERA NET+, etc.).

### 4.2 Collaborative research

Spain is very active in international research efforts and bilateral agreements. The government R&D program supports experts in Spain who lead IEA Wind Task 11 Base Technology Information Exchange, Task 27 Labeling Small Wind Turbines in Highly Turbulent Sites, and Task 31 Wakebench: Benchmarking Wind Farm Flow Models, a task led by Spanish experts in wind flow modeling in complex terrain.

There are also many Spanish entities participating in other IEA Wind research tasks as for example, Task 25 Power System with Large Amounts of Wind Power, Task 26 Cost of Wind Energy, Task 29 MexNext Aerodynamics, Task 30 OC5 Offshore Code Comparison Collaboration Continuation with Correlation, or Task 34 Environmental Assessment and Monitoring, Task 36 Forecasting for Wind Energy, and Task 37 Wind Energy Systems Engineering Integrated R, D&D.

**Table 2. 2015 R&D Budget, Grants, and Loans**

| Program | Total Budget (EUR; USD) | Grants and Loans (EUR; USD) |
|---|---|---|
| 2014 EEA Grants Projects (CDTI) | 16,453,100 EUR; 17,900,973 USD | 11,950,700 EUR; 13,002,362 USD |
| 2015 CIEN & IDL (CDTI) | 11,277,100 EUR; 12,269,485 USD | 8,613,800 EUR; 9,371,814 USD |
| 2015 RETO PPC (MINECO) | 8,595,575 EUR; 9,351,986 USD | 6,369,860 EUR; 6,930,408 USD |
| Total | 36,325,775 EUR; 39,522,443 USD | 26,934,360 EUR; 29,304,584 USD |

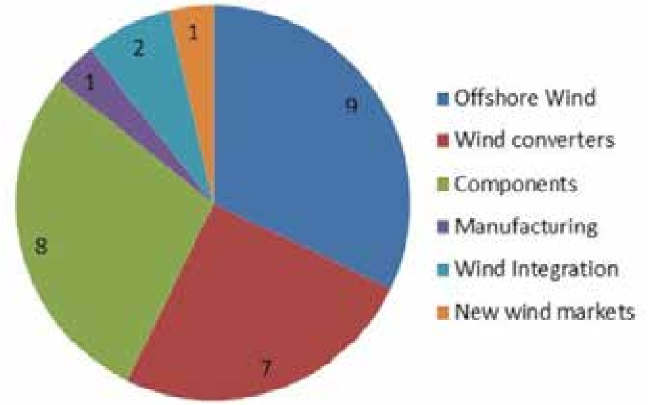

Figure 3. Number of projects in the main wind R&D areas in 2015

## 5.0 The Next Term

Spain has renewable energy targets agreed with the EU of 22.7% of final energy consumption. That means more new renewable energy capacity has to be installed, and the Ministry of Energy planning department agreed that 6,400 MW wind energy capacity should be added by 2020.

The future of wind energy in Spain presents some hope; 2016 is expected to be a more promising year after the tough situation experienced in the recent times. The new regulations to promote wind energy in the Canary Islands and on the Spanish mainland indicate a clear change in the government's position about wind energy. These regulations will continue the auction program for new wind capacity in Spain in 2016 and wind is cost competitive. In addition, electricity interconnection capacity is increasing, especially with the European power system, France, and with the Balearics Islands. This should gradually allow installed wind power capacity to increase on the Spanish mainland with guaranties.

Regarding the current Spanish wind turbine manufacturers, the trend is to establish merges between different players in order to be more competitive in the future global market. (Acciona Wind and Nordex, Gamesa, and Siemens Wind). In the future, the new challenges will be addressed by the suppliers.

Research should be directed to extension of the useful life time of the wind farms, the development of new techniques and innovative technologies to reduce costs of operation and maintenance of wind farms, and the development of more accurate solutions for wind resources assessment and forecasting. Also crucial is development of cost competitive floating platforms for offshore wind, the development of innovative components for the new very large wind turbines, the development of cost competitive manufacturing processes, and the development of new solutions for large wind energy integration into the grid. These are still important matters to research if the wind sector will continue to be a worldwide leader.

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Opening photo: Corral-Rico Lake (Photo credit: José Antonio López Rico)

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[6] *Wind Power 2015*. Reference yearbook of Spanish wind sector (Spanish), Asociación Empresarial Eólica (AEE; Spanish Wind Energy Association). June 2015 www.aeeolica.org/uploads/AEE__ANUARIO_2015_web.pdf

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# 37 Sweden

## 1.0 Overview

**The new wind energy installations in 2015 had a capacity of 604 MW (956 MW were installed in 2014). At the end of 2015, the total installed wind generation was 6,029 MW from 3,233 wind turbines. A major part of wind power research financed by the Swedish Energy Agency is carried out in the research programs Vindforsk, Vindval, Swedish Wind Power Technology Center (SWPTC), and Wind Power in Cold Climates [1]. Vindforsk focuses on wind resource and establishment, operation and maintenance, and wind power in the power system. Vindval is a knowledge program focused on studying the environmental effects of wind power. SWPTC's main objective is the design of an optimal wind turbine which takes the interaction among all components into account. The program Wind Power in Cold Climates focuses on removing barriers that arise for wind power in cold climates.**

## 2.0 National Objectives and Progress

On the basis of the EU burden-sharing agreement, Sweden is required to achieve a renewable energy share of 49% by 2020. Sweden has further raised this goal so that its renewable energy share should be at least 50% of the total energy use.

The green electricity certificate system is the major policy measure in increasing the share of renewables in Sweden. From 2011, a green electricity certificate system between Norway and Sweden is in place.

### 2.1 National targets

In 2008, the Swedish government expressed a planning framework of 30 TWh wind power by 2020, comprised of 20 TWh land-based and 10 TWh offshore. Within the electricity certificate system the goal is to increase renewable electricity generation by 26.4 TWh until 2020 compared to the level in 2012.

### 2.2 Progress

Electricity generation from wind power has increased from 11.6 TWh in 2014 to 16.6 TWh in 2015, as shown in Figure 1. The Swedish electricity end use in 2015 was 136 TWh. The wind power electricity generation share 2015 was 12.2 %.

### 2.3 National incentive programs

There are two main incentive programs for the promotion of wind power: electricity certificates and support for technical development in coordination with market introduction for large-scale plants offshore and in arctic areas. The work done in assessing areas of national interest for wind power can also be considered a sort of "soft incentive."

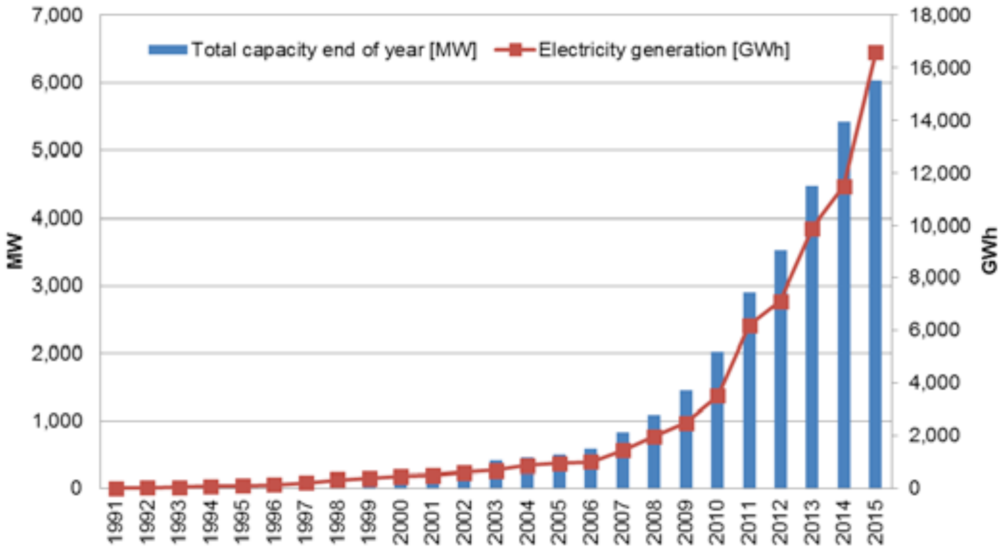

Figure 1. Installed wind power capacity in Sweden 1991 to 2015

### 2.4 Issues affecting growth

The expansion of wind power is mainly driven by the incentives within the electricity certificate system. Because of the last years lower prices of both electricity and certificates only the most profitable places is used for new wind farms.

## 3.0 Implementation

Wind power in mountainous terrain and cold climates is gaining more and more interest. Northern Sweden exhibits many such areas, where the wind potential is high. Wind turbines in the northern part of Sweden are facing a number of challenges not seen in areas with warmer climates. One such challenge is the risk of ice on the wind turbine blades, which will reduce production and may result in falling ice. Experiences from operation of wind power in cold climates indicate that energy losses due to ice buildup on wind turbine blades can be substantial.

It is a general understanding that wind turbines in such areas have to be equipped with special cold climate packages. Such

| Table 1. Key National Statistics 2015: Sweden | |
|---|---|
| Total (net) installed wind capacity | 6,029 MW |
| New wind capacity installed | 604 MW |
| Total electrical output from wind | 16.6 TWh |
| Wind-generated electricity as a % of national electric demand | 12.2% |
| Average national capacity factor | 33% |
| Target: | Planning framework of 30 TWh wind power by 2020 (20 TWh land-based and 10 TWh offshore) |

packages may include special steel qualities in towers and nacelle structures, and special types of oil and grease. The most essential thing is to equip blades with equipment for de-icing or anti-icing. To support the deployment in cold areas the Swedish Energy Agency is supporting a number of projects financially.

Concerning the industry, expansion of land-based wind power is mostly driven by large utilities like Vattenfall and E.ON, but also by others. A number of utilities, developers, real estate companies, and private persons are developing small and large projects.

Large international manufacturers of turbines have sales offices in Sweden, but there are no domestic turbine manufacturers. On the component side (supply chain), the value of manufactured goods is large. The market consists of subcontractors such as SKF (roller bearings and monitoring systems) and ABB (electrical components and cables). Subcontractors are mainly multinational companies, but smaller entities that find the wind power market relevant to their know-how are also established in Sweden.

## 4.0 R, D & D Activities

The publicly funded wind energy research in 2015 was mainly carried out within the research programs Vindforsk [2], Vindval [3], SWPTC [4] and Wind Power in Cold Climates [5].

The present period of Vindforsk runs from 2013 to 2016, with a total budget of 60 million SEK (6.5 million EUR; 7.1 million USD). The program is financed 50% by the Swedish Energy Agency and 50% by industry. Vindforsk is organized in three project packages: The wind resource and establishment; Operation and maintenance and Wind power in the power system.

Vindval is a knowledge program focused on studying the environmental effects of wind power. The Vindval program is financed by the Swedish Energy Agency and is administrated by the Swedish Environmental Protection Agency. The program runs through 2018 with a budget of 27 million SEK (2.9 million EUR; 3.2 million USD). The research project supported in Vindval are mainly projects relate to wind power impact on reindeers, golden eagles, marine life and noise annoyance from wind turbines.

The SWPTC runs from 2010 to 2017. The program is financed by the Swedish Energy Agency, by industry, and by Universities and has a total budget of 96 million SEK (10.5 million EUR; 11.3 million USD). The center focuses on complete design of an optimal wind turbine which takes the interaction among all components into account. SWPTC is organized in six theme groups: power and control systems; turbine and wind load; mechanical power transmission and system optimization; offshore; maintenance and reliability; and cold climates.

The program Wind Power In Cold Climates runs from 2013-2016. The program is financed by the Swedish Energy Agency and has a total budget of 32 million SEK (3.5 million EUR; 3.8 million USD). The program focuses on removing barriers that arise for wind power in cold climates.

## 5.0 The Next Term

The research programs Wind energy in Cold Climates, Vindval, Vindforsk, and SWPTC will continue during 2016. A lot of the expected growth in wind generation capacity will be in forest areas and also in the northern parts of Sweden in the "low-fields." The interest in those regions is prompted by the rather good wind potential as estimated by Swedish wind mapping. Substantial uncertainty, however, exists in the energy capture and loads of turbines in forested areas. The character of wind shear and turbulence is less explored in these areas and projects in the coming research program will be set up to increase the knowledge in this area. The SWPTC activities will continue developing wind turbines and to optimize maintenance and production costs.

**References and notes:**

Opening photo: Offshore wind turbines supplying electricity to Sweden. (Credit: Andreas Gustafsson, Swedish Energy Agency)

[1] www.energimyndigheten.se/en/ (English)
[2] www.energiforsk.se/program/vindforsk/ (Swedish)
[3] www.naturvardsverket.se/vindval (Swedish)
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[5] www.energimyndigheten.se/forskning-och-innovation/forskning/fornybar-el/vindkraft/program/vindkraft-i-kallt-klimat-2013-2016/ (Swedish)

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# 38 Switzerland

## 1.0 Overview

**At the end of 2015, 34 wind turbines of considerable size were operating in Switzerland with a total rated power of 60 MW. These turbines produced 101 GWh of electricity. Since 1 January 2009, a cost-covering feed-in-tariff (FIT) for renewable energy has been implemented in Switzerland [1]. This policy in promoting wind energy led to a boost of new wind energy projects. Currently, financing is requested for an additional 3,490 GWh under the FIT scheme. As in 2014, due to continuous obstacles in the planning procedures and acceptance issues, no turbines were installed in 2015 (Table 1).**

**In Switzerland, an ancillary industry for wind turbine manufacturers and planners has been developed, which acts mainly on an international level. One study estimates that the total turnover in 2010 was about 38.9 million EUR (42.3 million USD) and the wind industry employs about 290 people [2]. Wind energy research is conducted by the public research institutions, such as the Swiss Federal Institute of Technology in Zurich (ETHZ), as well as by experienced private companies. Research activities are internationally cross-linked, mainly in the fields of cold climate, turbulent and remote sites, and social acceptance.**

## 2.0 National Objectives and Progress

As a result of the devastating earthquake in Japan and the disaster at Fukushima, the Swiss government and parliament decided in autumn 2011 to decommission existing nuclear power plants at the end of their operational lifespan and to not replace them with new nuclear power plants. In order to ensure the security of electricity supply, the Federal Council, as part of its new Energy Strategy 2050, is placing emphasis on increased energy savings (energy efficiency) and—amongst other measures—the expansion of hydropower and new renewable energies [3].

Wind energy is an important element within this new strategy. Suisse Eole, the Swiss Wind Energy Association, is the leading institution on the use of wind energy in Switzerland and will play an even more important role in coordinating all activities in collaboration with the cantonal (state) authorities of energy, energy suppliers, and energy planners.

### 2.1 National targets

Within the new energy strategy 2050, the additional energy yield from renewable energy is estimated to be 22.6 TWh/yr. Wind energy should contribute 4 TWh/yr to these targets. The Swiss wind energy plan also identifies the calculated wind energy potential for Switzerland, based on the real wind conditions at the sites, and on the possible number of plants to be installed. The potential is outlined by time horizons as follows: time horizon 2020: 600 GWh; time horizon 2030: 1,500 GWh; time horizon 2050: 4,000 GWh [4]. By the end of 2015, the energy yield from operating wind turbines was 101 GWh; advanced projects may generate an additional 300 GWh in the near future.

Since the introduction of the FIT in 2009, projects with an estimated energy yield of 77 GWh are in operation and being supported under the scheme; additional projects with a potential energy yield of 2,050 GWh have been registered, and 1,450 GWh are on the waiting list.

### 2.2 Progress

Today, approximately 59% of Switzerland's overall electricity production comes from renewable sources, with hydropower by far the biggest contributor (95%). In 2015, no wind turbines were put in operation (including turbines for repowering). In total, 34 wind turbines of a considerable size are installed with a rated capacity of 60 MW. These turbines produced 108 GWh.

### 2.3 National incentive programs

The cost-covering FIT for renewable energy is the most significant measure. Renewable resources include hydropower (up to 10 MW), photovoltaics, wind energy, geothermal energy, biomass, and waste material from biomass. The additional cost of the FIT is financed by a levy on electricity consumption. Following the amendment of Swiss energy legislation, the levy was raised in the beginning of 2015 from 0.083 EUR/ kW (0.09 USD/ kWh) to 0.101 EUR/kWh (0.11 USD/kWh). This leads approximately to 550 million CHF (506 million EUR; 551 million USD) annually of available funds.

### 2.4 Issues affecting growth

Besides the limited finances within the FIT system, there are other issues affecting growth. The substantial potential of wind energy in Switzerland can only be achieved if the existing widespread acceptance of this technology can be maintained. The activities of the IEA Wind Task 28 Social Acceptance of Wind Energy Projects continue to play an important role.

Planning procedures and construction permits in Switzerland are still very time- and cost-intensive and the outcomes are often uncertain. Here the intensified activities concerning spatial planning of the cantons (states) will lead to a higher realization grade of the planned projects.

Based on the important changes in the FIT, a dramatic rise in players on the Swiss market occurred. Establishing a high quality reference standard for future projects will be a major challenge for the Swiss Wind Energy Association.

## 3.0 Implementation

### 3.1 Economic impact

A study estimates that the total turnover in wind energy in Switzerland in 2010 was about 38.9 million EUR (42.3 million USD) and wind industry employs about 290 people [2]. Another study of McKinsey from 2009 estimates the world-wide turnover of Swiss companies in the field of wind energy in the year 2020 of 8.6 billion EUR (9.4 billion USD) and 32,000 employees worldwide [6].

### 3.2 Industry status

The Swiss industry is active in several fields of wind energy: development and production of chemical products for rotor blades like resins or adhesives (Gurit Heberlein, Huntsman, Clariant); grid connection (ABB); development and production of power electronics like inverters (ABB, Integral Drive Systems AG, Vivatec, VonRoll Isola); services in the field of site assessments and project development (Meteotest, Interwind, NEK, New Energy Scout, Kohle/ Nussbaumer, etc.); and products like gearboxes (RUAG).

### 3.3 Operational details

Due to the specific wind regime in Switzerland (moderate wind speeds, turbulent sites, icing conditions, etc.) the average capacity factor for installations in Switzerland is below 20%. New projects with modern wind turbines are showing substantially higher performance, also thanks to lessons learned within research activities. The turbines in the lower Rhone Valley recorded over 2,500 full load hours, values similar to locations in Northern Germany and Denmark.

### 3.4 Wind energy costs

Since no new turbines have been built in 2015, the cost data for large wind power plants have not changed since 2013. It is about 1,450 EUR/ kW (1,578 USD/kW), and including installation the figure rises to 2,070 EUR/kW (2,252 USD/kW). The regulation for the compensatory FIT scheme provides 0.124 to 0.184 EUR/ kWh (0.135 to 0.200 USD/kWh) for wind energy—based on the same mechanism as the German model. Swiss participation in the IEA Wind Task 26 Cost of Wind Energy generated important information for this discussion.

## 4.0 R, D&D Activities

### 4.1 National R, D&D efforts

The Federal Energy Research Masterplan 2013–2016 [7] focuses in the field of wind energy on

- developing innovative turbine components for specific application in harsh climates;
- increasing availability and energy yield at extreme sites, optimizing the integration of wind energy into the grid; and
- increasing the acceptance of wind energy.

Implementation of pilot and demonstration projects is designed to increase market penetration of wind energy and close the gap between

**Table 1. Key National Statistics 2015: Switzerland**

| | |
|---|---|
| Total (net) installed wind capacity | 60 MW |
| New wind capacity installed | 0 MW |
| Total electrical output from wind | 0.1 TWh |
| Wind-generated electricity as a % of national electric demand | 0.1% |
| Target: | By 2020: 600 GWh;<br>2030: 1,500 GWh;<br>2050: 4,000 GWh |

Wind farm in Gütsch (Photo credit: ©SwissEole)

research activities and application in practice. In 2015, the budget for wind energy related R&D projects was approximately 505,200 EUR (549,658 USD). Within the national "SwissEnergy" program, approximately 1,380,000 CHF (1,269,600 EUR; 1,381,380 USD) were allocated to the wind energy sector for information activities, quality assurance measures, and for the support of regional and communal planning authorities. Several innovative research projects were underway in 2015.

Assessment method for wind turbine noise: comparison between modeling and measurement. The different evaluation methods of wind farm noise in Switzerland—computer modeling (for projected wind farms) or in-situ measurements (for existing wind farms) are often discussed by the concerned authorities and organizations. In order to improve the evaluation of the wind farm noise, this research project aimed to compare the current Swiss calculation method with the results of in-situ measurements of a wind park (located in Peuchapatte in the canton Jura).

The results showed that the average global sound level obtained from the measurements is higher than the values obtained by the modeling. With increasing wind speed ($v > 7 m/s$) the difference between measurement and modeling is particularly high. This big discrepancy between measurement and calculation results is principally due to the fact that the measured wind turbine noise is overrated by the presence of background noise (wind in the vegetation). In addition to those results, the research project validated a number of elements concerning in-situ measurement such as the choice of material, instrumentation, necessary length of the measurement period, documentation method or position of the measurement material.

Overview of international knowledge about the impact of wind turbines on birds and bats and specifications for Switzerland [8]: the objective of this project is to give an overview of the current international knowledge about the impact of wind turbines on birds of prey, other breeding bird species, migrating birds and bats with special attention to the Swiss context.

The following summarizes the main findings of the study. The extent of possible impacts is mainly determined by a combination of factors belonging to the occurring species and the respective location like the ecological and ethological context, thermal upwinds for soaring species, or differences during days and seasons. With regard to collision risk, birds of prey and other large species must be considered as especially affected since they collide more frequently in proportion to their population size and the number of casualties can more easily lead to population declines due to low reproduction rates.

Macro siting (choice of location) and micro siting (optimization of wind farm layout) are regarded as the most important measures for minimization of impacts. Some species may be kept out of the danger zone by avoidance of attraction, by luring away, or by deterrence. Temporal curtailment of turbine operation in periods of high flight activity is already common practice with regard to minimization of collision numbers of bats. Management of impacts can only be successful on a case-by-case approach. Uncertainties in the impact prognosis may be handled by a more adaptive management. This would complement the established hierarchy of mitigation—avoid, minimize, compensate—with monitoring in order to be able to modify certain mitigation measures depending on its outcome.

Development of a methodology for the creation of a wind cadaster in an alpine valley [9]: an accurate localization method of wind potential is crucial for a quick deployment of wind energy. Experience shows that this is especially challenging in mountainous regions because of an insufficient data basis. The statistical methods spatially interpolating data from different measurement stations that are usually used for the creation of wind cadasters do not provide satisfactory results for regions with complex topographies. A model including the physics of atmospheric airstreams was necessary in order to allow a simulation of the area's impact on them.

The objective of this project was to develop a methodology for the creation of a wind cadaster where the theoretic potential of wind energy per installed rotor surface ($kWh/m^2$) is captured. The second part of the project, also completed, consisted in applying the developed methodology to create a wind cadaster for two mountainous regions of Switzerland (canton St. Gallen and parts of canton Graubünden).

### 4.2 Collaborative research

In addition to IEA Wind Task 28 Social Acceptance of Wind Energy Projects, Switzerland participated in the IEA Wind Task 11 Base Technology Information Exchange, Task 19 Wind Energy in Cold Climates, Task 26 Cost of Wind Energy, Task 31 Wakebench: Benchmarking of Wind Farm Flow Models, and Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN).

## 5.0 The Next Term

If significant economic effects of wind energy for the Swiss industry are to be realized, a substantial rise in research and promotional activities is crucial. In 2012, the energy research concept 2013 to 2016 was being expanded by the Swiss Federal Office of Energy (SFOE). The following key issues were included:

- Quantifying production losses and downtimes due to icing; and implementation and evaluation of relevant measures, in collaboration with IEA Wind Task 19 Wind Energy in Cold Climates,
- Reducing energy production costs by increasing the full-load hours and reliability of turbines in harsh conditions and on sites with low wind speeds,
- Increasing the accuracy of energy yield estimates and improving the economics of wind parks,
- Reducing planning and installation costs by speeding up planning procedures and considering important acceptance issues, and
- Maintaining the high degree of wind energy acceptance in Switzerland.

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Opening photo: Wind turbine in Peuchapatte (Photo Credit: ©SwissEole)

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# 39 United Kingdom

## 1.0 Overview

The United Kingdom (UK) continued to increase its land-based and offshore wind capacity throughout 2015. Land-based capacity increased to over 8 GW and offshore capacity increased to over 5 GW. Growth in offshore wind installed capacity is expected to reach 10 GW by 2020.

The UK generates more electricity from offshore wind than any other country in the world, meeting around 5% of annual UK electricity requirements. Electricity generated from land-based and offshore wind was approximately 12% of the total electricity generated in the UK, delivering 40.44 TWh of electricity onto the national grid in 2015 [1].

The UK has more offshore wind turbines than the rest of Europe combined and continues to have significant potential for both land-based and offshore wind. The 2009 Renewable Energy Directive set a target for the UK to achieve 15% of its energy consumption from renewable sources by 2020. Both offshore and land-based wind already has made a significant contribution to achieving this target.

In 2014, the UK government completed the final stages of a significant new framework for the electricity generation sector with the first allocation of contracts under the Contract for Difference (CfD) scheme. Over 3 GW of offshore wind capacity was allocated and the first auction took place in February 2015 where 1,162 MW offshore wind capacity and 748 MW land-based wind capacity was allocated [2].

The Cost Reduction Monitoring Framework (CRMF) 2015 report, published March 2016, provided strong evidence that the cost of energy from offshore wind continued to fall through 2015 and remains on track to deliver the target of 100 GBP/MWh (135 EUR/MWh; 148 USD/MWh) by 2020.

The second annual CRMF report, delivered by the Offshore Renewable Energy Catapult (ORE Catapult) on behalf of the Offshore Wind Programme Board, shows that investment in turbine technology delivered significant cost benefits, but that further reduction will need to come from the innovations in the 'balance of plant,' such as foundations, cables, and substations. Investment in research and development, and manufacturing industrialization to deliver such improvements, the report warns, will only come with greater visibility of future rates of deployment and market size as the government sets out details of contracts for new offshore wind farms.

Progress continues in the supply chain. In November 2015 Siemens started construction of their turbine blade factory and service operation center at Green Port Hull. Due for completion in autumn 2016, it will provide around 1,000 jobs. MHI Vestas Offshore Wind has commenced recruitment for over 200 skilled jobs at their blade manufacturing facility on the Isle of Wight. The new positions have been created to fulfill the demand for DONG Energy's 258-MW Burbo Bank Extension project as well as future offshore projects.

The UK continues to play a leading role in technology innovation and cost reduction of wind energy. The ORE Catapult in Glasgow and its National Renewable Energy Centre in Blyth continue to be a champion for the development and testing of technology innovations for the sector. In terms of investment opportunities, the UK holds its place as the number one country for offshore wind in the Ernst Young Renewable Energy Country Attractiveness Index [3].

## 2.0 National Objectives and Progress

In 2009, the UK signed up to a target of 15% of its primary energy from renewable sources as its contribution to the European Union (EU) target of 20% of primary energy from renewables.

### 2.1 National targets

The Climate Change Act 2008 established a target for the UK to reduce its carbon emissions by at least 80% from 1990 levels by 2050. To ensure that regular progress is made towards this target, the Act also established a system of five-yearly carbon budgets and the first four leading to 2027, have been set in law. The UK is currently in the second period (2013–2017). The Committee on Climate Change recognized the progress made in installed capacity of land-based and offshore wind generation and the further contribution that it needs to make to achieve future carbon emission reduction targets.

National targets for the energy mix are not defined in the carbon budgets, but the Levy Control Framework provides an indication of capacity that is expected to be allocated. For offshore wind, the potential 2020 deployment is 8–16 GW dependent on a range of factors including industry cost reductions over time. For land-based wind, the potential 2020 deployment is 9–12 GW but this remains subject to future UK government policy.

### 2.2 Progress

The United Kingdom continued to increase its land-based and offshore wind capacity throughout 2015. Land-based capacity increased by 2.5% to 8.5 GW and offshore capacity increased by over 13% in the same period to just over 5 GW (see Figure 1). The higher rate of growth of offshore wind is expected to continue and is forecast to reach 10 GW of installed offshore wind capacity by 2020 [4].

UK electricity generation from wind was responsible for 40.44 TWh of electricity generation, representing 11.9% of total electricity generation—an increase in the last five years of 36% (see Figure 2). The National Grid confirmed a record annual share of wind energy for the sector. This follows a series of renewable energy records during 2015, with the end of year seeing a slew of records broken for quarterly, monthly, and weekly generation. In the three months between October and December 2015, 13% of the UK's electricity demand was met by wind. In December, a new monthly record was set with wind supplying 17% of Britain's electricity demand—and a new seven-day wind generation record with wind meeting 20% of the UK's electricity demand.

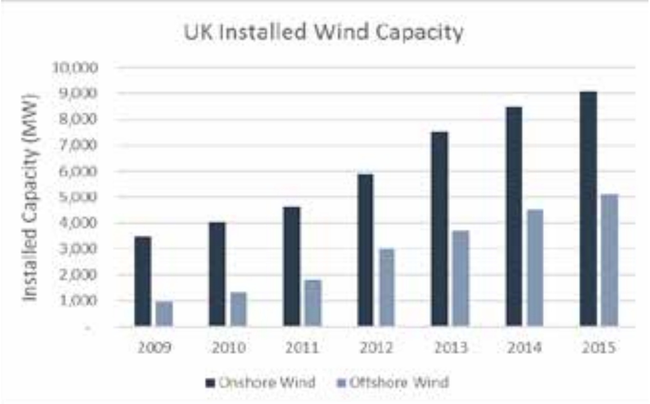

Figure 1. Installed wind capacity in the United Kingdom 2010 to 2015

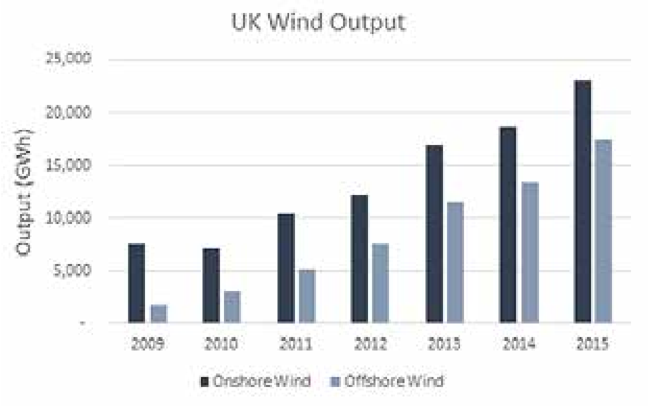

Figure 2. UK electricity generated from wind in the United Kingdom

### 2.3 National incentive programs

The UK government is committed to sourcing 15% of its energy from renewables by 2020 under the 2009 Renewable Energy Directive. The electricity generation contribution to this target will be driven by the Electricity Market Reform (EMR) program, introduced as part of the Energy Act 2013. This implements a new support system for all forms

| Table 1. Key National Statistics 2015: United Kingdom | |
|---|---|
| Total (net) installed wind capacity | 13,614 MW |
| New wind capacity installed | 806 MW |
| Total electrical output from wind | 40.44 TWh |
| Wind-generated electricity as a % of national electric demand | 12% |
| Average national capacity factor | 34% |
| Target: | 15% primary energy from renewables by 2020 |

of low carbon power beyond 2017. EMR changes the support for renewables from a fixed certificate price known as Renewable Obligation Certificates to a guaranteed strike price known as Contracts for Difference. A levy on energy bills will fund the difference payments from a day-ahead reference price.

#### 2.3.1 Contracts for Difference (CfDs)

CfDs will support new investment in all forms of low-carbon generation. The process has been designed to provide efficient and cost-effective revenue stabilization for new generation by reducing exposure to the volatile wholesale electricity price. A variable top-up from the market price to a pre-agreed 'strike price' is paid to generators. At times of high market prices, these payments reverse and the generator is required to pay back the difference between the market price and the strike price thus protecting consumers from over-payment. The strike price arrangements are higher for offshore wind compared with land-based, as the government seeks to encourage developers to construct new offshore windfarms where they have less visual impact.

An auction process is used to award CfDs to provide best value to the electricity consumer. A designated cap on the funding pot is used to provide control on the total cost of the program. Target strike prices have been set for 2018–2019, but there are no commitments for projects that are commissioned beyond this date. The first CfD auction took place in February 2015 where 1,162 MW offshore wind capacity and 748 MW land-based wind capacity was allocated. Out of the 27 successful projects, two were offshore wind and 15 were land-based wind [2].

In November 2015, the Rt Hon Amber Rudd, Secretary of State for Energy and Climate Change, stated in a speech that the offshore wind industry is supporting a growing installation, development, and blade manufacturing industry. Around 14,000 people are employed in the sector. Groundbreaking expertise has helped the costs of contracts for offshore wind come down by at least 20% in the last two years. But the technology needs to move quickly to cost-competitiveness. The UK could support up to 10 GW of new offshore wind projects in the 2020s. If the government's conditions on cost reduction are met, funding will be available for three auctions in this Parliament, the first of which is intended to be held by the end of 2016.

#### 2.3.2 Capacity market

The UK government introduced a capacity market allowing for capacity auctions from 2014 for delivery of capacity in the winter of 2018–2019 onwards to help ensure a sufficient supply, even at times of peak demand. The capacity market will provide an insurance policy against future supply shortages, helping to ensure that consumers continue to receive reliable electricity supplies at an affordable cost.

#### 2.3.4 Renewables Obligation (RO)

The Renewables Obligation is the existing incentive mechanism for eligible renewable electricity generation. It has been in operation since 2002, but it will be replaced by CfDs from 2017 onwards. The Renewables Obligation requires power suppliers to derive a specified portion of the electricity they supply to customers from renewable sources. Eligible renewable generators receive Renewables Obligation Certificates for each MWh of electricity generated and these certificates can then be sold to power suppliers in order to meet their obligation.

#### 2.3.5 Feed-In Tariff (FIT)

The FIT scheme was introduced on 1 April 2010, under the Energy Act 2008. In December 2015 changes to the FIT were announced by the UK government. Machines rated below 100 kW will receive 0.0854 GBP/kWh (0.116 EUR/kWh; 0.126 USD/kWh) in February 2016, a drop of nearly 38%. The Department of Energy and Climate Change also confirmed that it will retain a small level of support for turbines larger than 1.5 MW, offering 0.0086 GBP/kWh (0.0117 EUR/kWh; 0.127 USD/kWh) instead of ending the tariff all together, a cut of 65% from 2015 levels.

### 2.4 Issues affecting growth

The energy trilemma of sustainability, security of supply, and cost continues to present policy makers with a difficult balancing act. The change of government at the UK general election in May 2015 led to changes in the renewables sector strategy. The government intends to redirect funding to less mature technologies including offshore wind but will cut support to the land-based wind sector. Electricity market reform brought some clarity up to 2020 but the lack of commitment beyond 2020 presents increased risk for project developers and is a threat to investment throughout the supply chain. Land-based wind still faces additional challenges at the consenting stage with an increasing number of planning applications being called in for a decision by the Department for Communities and Local Government.

## 3.0 Implementation

The UK government published the Offshore Wind Industrial Strategy in July 2013 and this continues to provide the basis for industrial policy for the sector [3].

### 3.1 Economic impact

ORE Catapult published an in-depth assessment of the economic impact of the offshore wind sector in early 2014. The report concluded that for an accelerated growth deployment scenario of 15 GW of installed capacity by 2020, where UK companies seize the opportunity and innovate collaboratively, the gross value added can reach almost 6.7 billion GBP (9.1 billion EUR; 9.9 billion USD) in 2020, supporting 34,000 direct jobs and 150,000 jobs in total. With a gradual growth scenario to 8 GW installed in 2020, gross value added can reach 2.3 billion GBP (3.2 billion EUR; 3.4 USD) in 2020, with just under 12,000 direct jobs and 50,000 jobs supported in total [4].

### 3.2 Industry status

The Offshore Wind Industry Council commissioned a report, "The UK Offshore Wind Supply Chain: A Review of Opportunities and Barriers," published in November 2014. The report concluded that 43% of the lifetime cost of a UK wind farm is spent in the UK. Whilst manufacturing related to the turbines themselves remains largely in Germany and Denmark, the resources required for project management and installation have grown extensively in the UK. The report also noted that as much as 60% to 70% of the workforce deployed on the most recent projects have been UK based. Further, it concluded that over 6,800 people were directly employed in offshore wind in the UK [5].

The UK government introduced the requirement for supply chain plans within the CfD process to stimulate supply chain competition. It is hoped that the benefits of this approach will be realized in the next few years. Until recently, the UK did not have an established wind turbine manufacturer. However, in 2015, Siemens began construction of wind turbine production and installation facilities in the UK [6].

### 3.3 Operational details

For land-based wind, project sizes are declining overall. This is due partly to the growth of the sub-5-MW market under the FIT. Projects at this scale now make up two-thirds of new land-based submissions. Other factors include a reduction in the availability of larger sites and developers' responses to changes in the planning system.

The overall trend for capacity factors remains positive with an overall wind capacity factor of 34% for 2015. This is higher than 2014, and is likely to be a result of annual variations in the average wind speed.

The size of offshore wind farms has continued to increase; Dogger Bank Creyke Beck A and B offshore wind project was approved by the UK government in February 2015. The project will include up to 400 wind turbines and, with a maximum capacity of 2,400 MW, it will generate enough electricity to power almost 2 million homes.

**Table 2. Offshore wind projects by end of 2015**

| Wind Farm Name | First Power | Total Capacity (MW) |
|---|---|---|
| Blyth | 2000 | 4 |
| North Hoyle | 2003 | 60 |
| Scroby Sands | 2004 | 60 |
| Kentish Flats | 2005 | 90 |
| Barrow | 2006 | 90 |
| Beatrice Demonstration | 2007 | 10 |
| Burbo Bank | 2007 | 90 |
| Inner Dowsing | 2008 | 97 |
| Lynn | 2008 | 97 |
| Rhyl Flats | 2009 | 90 |
| Gunfleet Sands I + II | 2009 | 173 |
| Robin Rigg | 2009 | 180 |
| Thanet | 2010 | 300 |
| Greater Gabbard | 2010 | 504 |
| Ormonde | 2011 | 150 |
| Walney Phase 1 | 2011 | 184 |
| Walney Phase 2 | 2011 | 184 |
| Sheringham Shoal | 2011 | 317 |
| Lincs | 2012 | 270 |
| London Array Phase 1 | 2012 | 630 |
| Teesside | 2013 | 62 |
| Gwynt y Môr | 2013 | 576 |
| West of Duddon Sands | 2014 | 389 |
| Westermost Rough | 2014 | 210 |
| Humber Gateway | 2015 | 219 |
| Kentish Flats Extension | 2015 | 50 |

### 3.4 Wind energy costs

A second assessment of offshore wind costs was carried out in 2015 under the CRMF. It concluded that the offshore wind sector was progressing at the required pace to achieve a levelized cost of energy of 100 GBP/MWh (136 EUR/MWh; 148 USD/MWh) for projects reaching a Final Investment Decision in 2020 [7], [8].

## 4.0 R, D&D Activities

The UK continues to play a leading role in technology innovation and cost reduction of wind energy and ORE Catapult continues to champion the development and testing of technology innovation for the sector.

### 4.1 National R, D&D efforts

The Crown Estate awarded lease agreements to three offshore wind demonstration sites:

- Gunfleet Sands extension—DONG Energy for testing up to two next-generation offshore wind turbines.
- Blyth Offshore Wind demonstration site—ORE Catapult for a 100-MW site to test and demonstrate up to 20 next-generation offshore wind turbines and associated infrastructure.
- European Offshore Wind Deployment Centre—Aberdeen Offshore Wind Ltd, a company owned 75% by Vattenfall and 25% by Aberdeen Renewable Energy Group (AREG) to test and demonstrate up to 11 next-generation offshore wind turbines and other technology in Aberdeen Bay.

#### 4.1.1 The Offshore Renewable Energy Catapult

The ORE Catapult has world-leading test and research facilities. These include a 15-MW drive train test facility, 50-m and 100-m blade test facilities, a 3-MW tidal turbine drive train test facility, three dry dock facilities and a UKAS-accredited electrical and materials laboratory. With the engineering team's specialized skills and industry experience, ORE Catapult provides the necessary support to get new technologies ready for deployment. The facilities provide a controlled environment to perform accelerated life testing, improve reliability, and reduce costs of offshore renewable energy technologies in the UK.

In spring 2015, ORE Catapult launched the SPARTA (System Performance, Availability and Reliability Trend Analysis) secure database of offshore wind farm performance data, developed from a collaboration with The Crown Estate and offshore wind farm owner and operators, which will improve wind turbine operational performance by increasing safety, reliability, and availability.

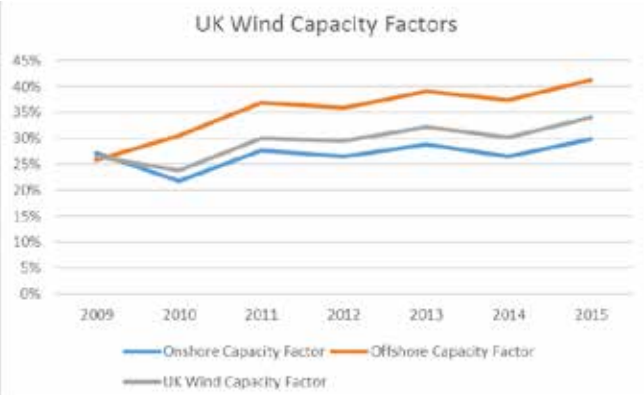

Figure 3. Average capacity factor for wind in the United Kingdom

A briefing event for the Blade Leading Edge Erosion Programme (BLEEP) Joint Industry Project (JIP) was held in August 2015 and was attended by most of the large blade manufacturers and O&M companies. The project was initiated by ORE Catapult and aims to accelerate the commercial development of solutions to erosion of the leading edge of blades. It uses outputs from a targeted measurement campaign with detailed analysis of wind farm data to reduce the impact of erosion on the cost of energy.

On 15 December 2015, ORE Catapult completed the acquisition of the Levenmouth 7-MW demonstration offshore wind turbine, located off the East Fife Coast of Scotland, from Samsung Heavy Industries (SHI). This is the world's most advanced open access offshore wind turbine dedicated to research and product validation. It also offers complementary opportunities for training and development of skills vital for the future of the offshore wind industry.

#### 4.1.2 Delivery of the Cost Reduction Monitoring Framework

The second annual CRMF report was released at the same time as the UK Parliament review of the Fifth Carbon Budget of the Committee on Climate Change, which projects that offshore wind costs will be below new nuclear and new gas plants by 2025. The Offshore Wind Programme Board said: "Offshore wind is delivering jobs and economic benefit to the UK right now. This report shows that consumers and Government can be confident that the cost of offshore wind will continue to reduce and that offshore wind is the ideal way to produce the large quantities of clean, reliable energy that the UK needs."

Of the 13 cost reduction indicators in the report, all but one are ahead or on target with the milestone set in 2015. Findings show that industry has already adopted innovations that were not previously expected to significantly drive cost reduction until 2017, particularly in the areas of turbine design and project maintenance. The report also assessed the degree of confidence that the industry has in delivering further cost savings. It found high confidence of delivery in eight of the indicators, with medium confidence in a further three, to achieve the milestone of 100 GBP/MWh (135 EUR/MWh; 148 USD/MWh) in 2020.

#### 4.1.3 Research Councils UK Energy Programme

Each year, UK Research Councils invest around 3 billion GPB (4.1 billion EUR; 4.4 billion USD) in research covering the full spectrum of academic disciplines. They support research that has an impact on the growth, prosperity, and wellbeing of the UK. To maintain the UK's global research position they offer a diverse range of funding opportunities, foster international collaborations, and provide access to the best facilities and infrastructure around the world. Research Councils also support the training and career development of researchers. The Industrial Doctorate Centre in Offshore Renewables, with more than 50 students, is playing a key role in training professionals in areas which are important to the industry. To maximize the impact of research, they work in partnership with other research funders including InnovateUK, UK Higher Education Funding Councils, business, government, and charitable organizations.

The Energy Programme has invested more than 625 million GBP (847 million EUR; 922 million USD) in research and skills to pioneer a low carbon future. The Energy Programme is led by the Engineering and Physical Sciences Research Council (EPSRC).

The EPSRC established the SUPERGEN Wind Energy Technologies Consortium (SUPERGEN Wind) in 2006 as part of the Sustainable Power Generation and Supply (SUPERGEN) program. The SUPERGEN Wind Consortium is led by Strathclyde and Durham Universities and consists of seven research groups with expertise in wind turbine technology, aerodynamics, hydrodynamics, materials, electrical machinery and control, and reliability and condition monitoring.

#### 4.1.4 InnovateUK

InnovateUK is an executive, non-departmental public body established by the government in 2007 and sponsored by the Department for Business, Innovation and Skills (BIS). InnovateUK activities are jointly supported and funded by BIS and other government departments, the devolved administrations, and research councils. InnovateUK aims to accelerate innovation by helping UK businesses to innovate faster and more effectively than would otherwise be possible, using its expertise, connections, and funding. Other programs like GROW have also contributed to the development of offshore wind [9].

#### 4.1.5 Energy Technologies Institute (ETI)

The Energy Technologies Institute (ETI) is a public-private partnership between global energy and engineering companies—BP, Caterpillar, EDF, E.ON, Rolls-Royce, and Shell—and the UK government.

The ETI carries out three key activities:

- modelling and analysis of the UK energy system to identify the key challenges and potential solutions to meeting the 2020 and 2050 targets at the lowest cost to the UK,
- investing in engineering and technology development and demonstration projects which address these challenges with the aim of de-risking solutions—both in technology and in supply-chain development—for subsequent commercial investors, and
- providing deployment support to enable rapid commercialization of products.

#### 4.1.6 Offshore Wind Programme Board

The Offshore Wind Programme Board was established by the Secretary of State for Energy and Climate Change in November 2012 to build on extensive work on the cost reduction potential of the offshore wind sector. The Board aims to deliver cost reduction and enable growth of a competitive UK-based supply chain as the industry grows and matures. The Board's role is to identify and remove barriers to deployment of offshore wind generation, to share best practice across industry, and to bring forward innovative and collaborative solutions to build a competitive UK-based supply chain—supporting delivery of a levelized cost of energy of 100 GBP/MWh (135 EUR/MWh; 148 USD/MWh)for projects reaching a Final Investment Decision in 2020.

#### 4.1.7 Offshore Wind Accelerator

The Offshore Wind Accelerator is a collaborative R, D&D program bringing together nine offshore wind developers to work towards reducing the cost of offshore wind. One third is funded by the UK government and two thirds from the industry. The research development and demonstration program focuses on five areas:

- Foundations: developing new turbine foundation designs for 30–60 m water depths that are cheaper to fabricate and install
- Access systems: developing improved access systems to transfer technicians and equipment onto turbines for operations and maintenance in heavier seas
- Wake effects: improving the layout of large wind farms to reduce wake effects and optimize yields
- Electrical systems: developing new electrical systems to reduce transmission losses and increase reliability
- Cable installation: improving cable installation methods

#### 4.1.8 The Low Carbon Innovation Co-ordination Group (LCICG)

The LCICG brings together the major public-sector backed funders of low carbon innovation in the UK. Core members include the Department of Energy and Climate Change, BIS, Carbon Trust, Energy Technologies Institute, Technology Strategy Board, the Engineering and Physical Sciences Research Council, the Scottish government, and the Scottish Enterprise.

The group's aim is to maximize the impact of UK public sector funding for low carbon energy in order to:

- deliver affordable, secure, sustainable energy for the UK,
- deliver UK economic growth, and
- develop UK's capabilities, knowledge and skills.

The LCICG has commissioned an update of the Technology Innovation Needs Assessment of a range of low carbon technologies including offshore wind.

### 4.2 Collaborative research

There are a number of major collaborative EU research projects that the UK is participating in. LEANWIND's (Logistic Efficiencies and Naval Architecture for Wind Installations with Novel Developments) primary objective is to provide cost reductions across the offshore wind farm lifecycle and supply chain through the application of lean principles and the development of state of the art technologies and tools.

The Demonstration of Methods and Tools for the Optimisation of Operational Reliability of Large-Scale Industrial Wind Turbines (OPTIMUS), is an FP7 research project being led by ORE Catapult to develop and demonstrate novel strategies to enable the prognosis of the remaining lifetime of key wind turbine components.

The MAterials and REliability in offshore WINd Turbines technology (MAREWINT) is an FP7 funded project. Its Initial Training Network will provide a structured, integrated, and multidisciplinary training program for the future offshore wind turbine technology experts. The consortium is composed of public and private organizations and based on a common research program; it aims to increase the skills exchange between the public and private sectors.

## 5.0 The Next Term

With a forecast installed base of over 20 GW the wind sector has established itself as a significant contributor to sustainable and secure energy and has demonstrated that with the right investment in innovation, costs can be reduced further. The second report from the CRMF provided strong evidence that the offshore wind sector in the UK is on track to reach 100 GBP/MWh (135 EUR/MWh; 148 USD/MWh) by 2020 and showed that there is a continued path for further cost reductions beyond that.

Electricity Market Reform has helped to reduce financial risk up to 2020 but the lower than forecast capacity allocation and the lack of certainty beyond 2020 could impact investment in new technology and slow down further technology development that is necessary for cost reduction.

The United Kingdom remains a world-leader in the wind sector and in 2015 made progress in terms of growth of installed capacity and electricity generated. The potential for the sector to deliver economic growth and significant employment has been demonstrated. The sector must work closely with policy makers in 2016 to ensure these benefits will be realized.

**References:**

Opening photo: ORE Catapult's 7-MW offshore wind demonstration turbine located at Levenmouth in Fife, Scotland. The turbine is the world's most advanced open access offshore wind turbine dedicated to research and product validation. (Photo credit: ORE Catapult)

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# 40 United States

## 1.0 Overview

The U.S. wind industry experienced a momentous year in 2015. In March, the U.S. Department of Energy Wind Program (DOE) released its landmark Wind Vision: A New Era for Wind Power in the United States, which establishes wind energy goals of 10% of the nation's electricity in 2020, 20% in 2030, and 35% in 2050 [1].

By year's end, the United States had installed 8,598 MW of new capacity—a 77% increase over total installations during 2014. The nation's cumulative wind energy capacity now stands at 73,992 MW and provides 5.1% of the nation's electrical demand. According to the American Wind Energy Association (AWEA), the United States produced more wind energy during 2015 than any other country—190.1 million MWh of electricity, which is enough to power 17.5 million average U.S. homes, and saved the equivalent of 131.7 million metric tons of carbon dioxide in 2015 [2, 3].

The 30-MW Block Island Wind Farm project—the first U.S. commercial offshore wind project—began construction in 2015 and DOE deployed the AXYS WindSentinel buoy off the coast of New Jersey. DOE also published three offshore wind reports in 2015 that provided detailed analyses of various aspects of the U.S. offshore wind market to help inform future offshore wind development [4].

U.S. distributed wind capacity installed since 2003 now totals 934 MW, representing more than 75,000 turbines. Of the 8,598 MW of wind projects installed in 2015 using turbines greater than 100 kW, 23.7 MW were installed in distributed applications. At least 4.3 MW of small wind (<100 kW) was deployed in the United States in 2015, totaling 1,695 turbines and over 21 million USD (19 million EUR) in investment. This is slightly higher than 2014, but down from 2013 [5].

Technological advancements made in 2015, such as taller wind turbine towers of 110 and 140 meters and larger rotors, will help the United States more efficiently capture the stronger and more consistent wind resources typically found at greater heights [6].

## 2.0 National Objectives and Progress

Wind power is a key component of the Obama Administration's all-of-the-above approach to U.S. energy—a strategy that helps reduce carbon emissions, diversifies the U.S. energy portfolio, enhances energy security, and supports jobs. In March 2015, DOE released the landmark *Wind Vision: A New Era for Wind Power in the United States*, which envisions a new future for wind energy through 2050. The analysis concludes that with continued investment in technology innovations and transmission system expansions, the ambitious deployment scenarios in the *Wind Vision* are viable [1].

### 2.1 National targets

The *Wind Vision* defines the following benchmark goals for U.S. wind energy: to supply 10% of the country's electricity in 2020, 20% in 2030, and 35% in 2050. President Obama announced during the 21st meeting of the Conference of Parties (COP21) in December 2015 that the United States will address climate change by reducing its carbon emissions 26% to 28% below 2005 levels by 2025 [1, 7].

### 2.2 Progress

U.S. wind capacity at the close of 2015 was 73,992 MW, with more than 9,400 MW of wind under construction and an additional 4,900 MW in advanced stages of development. Wind generated a total of 190.1 million MWh of electricity in 2015—enough to power 17.5 million average U.S. homes and saving the equivalent of 131.7 million metric tons of carbon dioxide in 2015 [2, 3]. The 8,598 MW of capacity installed during 2015 represented a 77% increase over 2014 total installations. Wind energy supplied 5.1% of the nation's electrical demand in 2015 [2]. More than 4,300 turbines were installed across 64 projects in 20 states in 2015, bringing the total fleet to more than 48,500 operating wind turbines [2].

### 2.3 National incentive programs

Although federal and state incentives have helped stimulate the growth of the wind industry, one of the most impactful federal incentives for utility-scale development in the past has been the renewable energy Production Tax Credit (PTC). Originally enacted in 1992, the PTC is an inflation-adjusted per-kilowatt-hour tax credit for electricity generated by qualified facilities [8]. The PTC expired in January 2015. In December 2015, the Consolidated Appropriations Act extended the PTC expiration date to 31 December 2019, with a phase-down for wind projects commencing construction after 31 December 2016. The Act applies retroactively to 1 January 2015 [8].

The federal Business Energy Investment Tax Credit (ITC), which expires at the end of 2016, currently allows for a 30% credit on the cost of development for large wind systems and a 30% credit for development of distributed wind systems with capacity ratings of less than 100 kW with no maximum credit for small wind turbines placed in service after 31 December 2008. The credit for turbines up to 2 MW in capacity is capped at 200 USD (184 EUR) per kW of capacity. The expiration date for wind technologies is based on when construction begins [8].

Other federal incentives include the Tribal Energy Grant Program that supports renewable energy efforts on Native American lands; the High Energy Cost Grant Program that funds the installation of wind turbines in rural areas; and the Rural Energy for America Program, which provides both grants and loans to agricultural producers and small businesses in rural areas [8].

On the local level, states and other municipal authorities may institute renewable portfolio standards (RPS) requiring utilities to purchase some percentage of their power from renewable sources. These standards have been a major driver of wind energy deployment. As of October 2015, 29 states, the District of Columbia, Puerto Rico, the Northern Marianas Islands, and the U.S. Virgin Islands have RPS. Another eight states and Guam have renewable portfolio goals, which are similar to RPS policies but are not legally binding. Other factors that encourage wind deployment include carbon-reduction policies, customer demand for renewable power, utility requirements, and local funding [8].

### 2.4 Issues affecting growth

Factors affecting growth of the U.S. wind industry in 2015 included uncertainties around extending the federal PTC, transmission and integration, environment, public acceptance, and the cost and risk of offshore wind energy.

#### 2.4.1 Extension of the PTC

The PTC expired in January 2015 and was not extended until December 2015. While the Act applied retroactively to 1 January 2015, uncertainty surrounding the PTC extension failed to incentivize development in 2015 and may have negatively impacted long-term wind industry growth because the planning and permitting process for a wind plant can take up to two years or longer to complete.

#### 2.4.2 Transmission and integration

Wind deployment growth has been impeded in some areas by a lack of access to transmission. While California is reopening its Renewable Energy Transmission Initiative process, the California Independent System Operators issued a 2015–2016 transmission plan that does not include proposed interregional transmission lines that would import power from wind-rich resource areas elsewhere in the West. Instead, the California Independent System Operators has signaled a preference to study such transmission projects on an interregional basis in conjunction with neighboring planning entities. In Texas, the Electric Reliability Council ended 2015 with 16 GW of wind online (compared with 12.5 GW at the beginning of 2014), 10 GW ready to go with signed interconnection agreements, and another 13 GW in the study queue [9].

As with all countries, the United States faces integration challenges from wind-generation variability and cycling impacts on fossil-fuel power plants. With the goal of developing detailed estimates of the impact of cycling on plant cost, DOE funded a comprehensive study in collaboration with the Western Electricity Coordinating Council. Using a large-scale, detailed, electricity-production simulation model, the overall cost of cycling was calculated for several high wind and solar penetration levels. The study found that fuel costs in the Western United States would decline by 7 billion USD (6.4 billion EUR). Calculated cycling costs ranged from 35 million USD to 157 million USD (32 million EUR to 144 million EUR) [9].

**Table 1. Key National Statistics 2015: United States**

| | |
|---|---|
| Total (net) installed wind capacity | 73,992 MW |
| New wind capacity installed | 8,598 MW |
| Total electrical output from wind | 190.1 TWh |
| Wind-generated electricity as a % of national electric demand | 5.1% |
| Average national capacity factor | 32% |
| Target: | Wind energy to supply 10% of the country's electricity by 2020, 20% by 2030, and 35% by 2050 |

2.4.3 Environment

As with all energy supply options, wind energy development can have adverse environmental impacts, including the potential to reduce, fragment, or degrade wildlife habitat. Furthermore, spinning turbine blades can pose a threat to flying wildlife such as birds and bats. Following proper siting practices can reduce these impacts, but does not completely eliminate risk. DOE invests in projects that seek to address these issues and supports environmentally sustainable development of wind power in the United States. Published in 2015, the Mid-Atlantic Wildlife Studies report is a first-of-its-kind, in-depth study of wildlife distribution and movements along the nation's Eastern Seaboard to help improve understanding of how birds and aquatic animals interact with their marine environment and to promote more sustainable offshore wind development. Also in 2015, DOE funded five technology development projects seeking to advance new concepts and refine near-commercial bat impact minimization technologies, such as ultrasonic acoustic deterrents, to dissuade bats from flying in the area of a wind turbine.

2.4.4 Public acceptance

The United States continues to experience social resistance to wind installations because of perceived or actual visual and acoustic impacts, interactions of wildlife with wind technology, and radar interference. In 2015, DOE continued to support efforts to identify and mitigate these issues. One example is the Wind Turbine Radar Interference Mitigation Working Group, a consortium of federal agencies comprising the U.S. Department of Defense, DOE, the Federal Aviation Administration, and the National Oceanic and Atmospheric Administration, which is working to address wind turbine radar interference and overcome these challenges so that wind development and radar missions can coexist.

2.4.5 Offshore wind cost and risk

The most pressing challenge faced by the U.S. offshore wind industry is the current high cost of offshore wind generation and the related lack of available Power Purchase Agreements (PPAs) and/or state and federal policies to support the development of the industry. Cost reduction is driving U.S. efforts to optimize technology and processes throughout the entire project life cycle, spanning development, construction, and operations. In addition, DOE's technology development projects are intended to produce innovative components, controls, and integrated system designs, as well as improved modeling and analysis tools, that will improve the performance and reliability and reduce the costs of offshore wind systems.

## 3.0 Implementation

Of the 8,598 MW installed by the U.S. wind industry in 2015, Texas installed the most capacity—1,307 MW. Oklahoma followed with 853 MW, Kansas with 599 MW, and Iowa with 502 MW. Texas also led the nation in installed capacity, with 17,711 MW—more than twice the installed capacity of any other state. Iowa ranked second in the nation, with 6,209 MW of installed capacity. California was third with 5,662 MW, and Oklahoma was fourth with 5,184 MW [2].

A DOE report released in September 2015 indicated strong progress for the U.S. offshore wind market. Deepwater Wind's Block Island Wind Farm, the first commercial wind farm in the United States, will feature five 6-MW turbines when it comes online in 2016 (Figure 1) [2]. Block Island is one of 21 projects totaling 15,650 MW in the planning and development pipeline. Of these 21 U.S. projects, 13 totaling nearly 6,000 MW—enough to power 1.8 million homes—are in the more advanced stages of development, while 12 projects with more than 3,300 MW planned have announced a commercial operation date by 2020. With 80% of the nation's electricity demand coming from coastal states, offshore wind could play a crucial role in meeting U.S. energy needs [10].

### 3.1 Economic impact

According to AWEA, in the last ten years the U.S. wind industry has generated more than 128 billion USD (117.6 billion EUR) in private investments. In 2015, 14.7 billion USD (13.5 billion EUR) were invested into new wind energy projects and, by the end of the year, more than 9,400 MW of wind energy capacity were under construction across 72 projects. The wind energy industry created more than 10,000 new jobs in the U.S. workforce in 2015, bringing the total number of people employed to 88,000 (21,000 in the manufacturing sector) [2]. The U.S. Bureau of Labor Statistics identified "wind turbine technician" as the country's fastest-growing profession [11].

The increasing use of wind generation and other sources of renewable energy is translating into lower monthly utility bills. Electricity rates across the nation have remained 5.5% lower than they were in 2009. At 0.071 USD/kWh (0.065 EUR/kWh), the retail price of electricity for the industrial sector in the United States is lower than in other major economies such as Germany, China, and India [12].

### 3.2 Industry status

At the end of 2015, there were more than 500 wind-related manufacturing facilities across 43 states, producing everything from major components such as blades, nacelles, and towers to bearings, fasteners, and sensors. GE Renewable Energy led the wind turbine manufacturing sector in 2015, capturing 40% of the cumulative market share of installed turbines, followed by Vestas with 33%, and Siemens with 14% [2]. U.S.-based small wind turbine manufacturers continued to focus on international markets as a source of revenue. Six manufacturers exported at least 21.5 MW in 2015 with an estimated 122 million USD (112 million EUR) value—almost twice the capacity and value of 2014 exports [5].

Overall, U.S. wind manufacturing supported more than 21,000 U.S. jobs at the end of 2015 [2]. More than 4,000 MW of PPAs were signed during 2015. Approximately 75% of the 1,800 MW contracted through PPAs during the fourth quarter were through publicly held companies such as Procter & Gamble, General Motors, and Google Energy. Utilities purchased more than 2,300 MW in the fourth quarter through PPA contracts [13].

### 3.3 Operational details

In 2015, more than 4,300 turbines were installed across 64 projects in 20 states. At the end of the year, the United States had 73,992 MW of installed wind capacity and more than 48,500 operating wind turbines. The capacity-weighted average project size was 201 MW and the average turbine size was 2 MW. The average rotor diameter of the turbines installed in 2015 was 102 meters and the average hub height was 82.3 meters [2]. The average U.S. capacity factor in 2015 was 32%.

Figure 1. Deepwater Wind's Block Island Wind Farm (Photo credit: Deepwater Wind)

### 3.4 Wind energy costs

According to the Lawrence Berkeley National Laboratory, data based on a limited sample of recently announced U.S. turbine transactions shows the current wind turbine price per kilowatt in the 850–1,250 USD (781–1,149 EUR) range.

## 4.0 R, D&D Activities

The DOE leads the nation's efforts to accelerate the deployment of wind power technologies through improved performance, lower costs, and reduced market barriers. The program works with industry partners, national laboratories, universities, and other federal agencies to conduct research, development, and demonstration (R, D&D) activities through competitively selected, directly funded, and cost-shared projects that produce innovative technologies for land-based, offshore, and distributed wind applications. The total budget for wind energy R, D&D in 2015 was 107 million USD (98 million EUR) [14].

### 4.1 U.S. R, D&D efforts

In 2015, DOE published the *Wind Vision*, which includes a roadmap for addressing the challenges to achieving 35% wind energy by 2050 and which informs DOE R, D&D investments. Key R, D&D efforts during the year included work to optimize wind plant performance through the multi-year Atmosphere to Electrons initiative, mitigate radar interference, improve gearbox and blade reliability, and enable better wind forecasting. In addition, DOE and its private-sector partners are working on technological advancements that include taller wind turbine towers and larger rotors, whose immense scale enables them to capture the stronger and steadier wind resources typically found at greater heights and generate electricity more efficiently than ever before.

4.1.1. Offshore wind R&D

For offshore wind energy, the *Wind Vision* describes a scenario where an offshore wind market and supply chain is established by 2020, 22 GW are installed by 2030, and 86 GW are installed by 2050. DOE funded advanced technology demonstration projects with the aim of deploying demonstration-scale offshore wind projects in U.S. waters. These projects explore the potential of deploying cost-reducing innovative offshore wind technology off both the Atlantic and Pacific coasts.

In 2015, DOE deployed the AXYS WindSentinel buoy off the coast of New Jersey, which complements a buoy deployed off the coast of Virginia in 2014. These high-tech research buoys use light detection and ranging (lidar) and other meteorological and oceanographic instruments to measure wind speed and direction. They also record air and sea surface temperature, barometric pressure, relative humidity, wave height and period, water conductivity, and subsurface ocean currents.

Fishermen's Energy and Keystone Engineering are re-evaluating workers' access to offshore wind turbine platforms by demonstrating an innovative ladder that is rotated 90 degrees compared to traditional access ladders, enabling the vessel deck to be placed as close as possible to the ladder rail and allowing the offshore worker to safely side step onto the ladder [1, 4].

DOE published three offshore wind reports in 2015. The *Offshore Wind Jobs and Economic Development Impacts in the United States: Four Regional Scenarios* report provides four case studies of potential offshore wind deployment scenarios in different regions of the United States: the Southeast, the Great Lakes, the Gulf Coast, and the Mid-Atlantic. The *2014–2015 U.S. Offshore Wind Technologies Market Report* provides data and analysis to assess the status of the U.S. offshore wind industry through 30 June 2015. The *Offshore Wind Projects* report summarizes the Wind and Water Power Program's offshore wind energy projects from fiscal years 2006 to 2015 [4].

4.1.2 Wind research and test facilities

In 2015, DOE launched a user-friendly online information resource portal, the Wind Technology Resource Center, which provides a central repository for research reports, publications, data sets, and online tools developed by DOE's national laboratories and facilities.

Two state-of-the-art wind turbine drivetrain test facilities opened for business: the Clemson University Wind Turbine Drivetrain Testing Facility in South Carolina and a National Renewable Energy Laboratory (NREL) dynamometer at the National Wind Technology Center in Colorado. These facilities provide a controlled environment for evaluating the mechanical and electrical systems that convert the aerodynamic forces of wind turbine blades into electricity and help accelerate the development and deployment of next-generation technologies for both offshore and land-based wind energy systems. Also under development in 2015, Sandia National Laboratories' Scaled Wind Farm Technology Facility, hosted at Texas Tech University, will help researchers understand the complex wind flow and wakes within a wind plant.

### 4.1.3 Emerging technology applications

In 2015, two DOE-funded research projects helped improve drivetrain reliability. Researchers at DOE's Argonne National Laboratory used the Advanced Photon Source—the brightest synchrotron x-ray source in the western hemisphere—to investigate the root cause of white-etch cracks, which are one of the leading causes of drivetrain bearing failures. NREL engineers assembled a wind turbine drivetrain that combined innovations across the entire drivetrain system, including the gearbox, generator, and power converter. Once testing is complete, these drivetrain technologies will improve wind turbine drivetrain reliability while significantly lowering operations, maintenance, and deployment costs.

Researchers from the National Wind Technology Center at NREL developed a lidar feedforward controller that is able to regulate wind turbines by "looking ahead" at incoming wind conditions, potentially eliminating the delay between sensing wind conditions and controlling turbine dynamics. Optimal regulation of rotor speeds in response to wind conditions is essential to capturing maximum wind energy while causing minimum load, offering more energy generation and longer-lasting turbines.

In 2015, DOE launched the multi-year Atmosphere to Electrons research initiative with a goal of ensuring future wind plants are sited, built, and operated in a way that produces the most cost-effective, usable electric power. To achieve this goal, a collaborative of scientists from DOE national laboratories, industry, and academia formed to assemble an unprecedented understanding of the wind plant operating environment.

The DOE-funded Wind Forecasting Improvement Project in Complex Terrain (WFIP 2) field campaign began in 2015, with 56 different meteorological instruments collecting data in the Columbia River Gorge region of Washington and Oregon. A team comprising four DOE national laboratories, the National Oceanic and Atmospheric Administration, and a private company, Vaisala, will use the collected data to support model development work aimed at improving short-term and day-ahead (up to 45 hours) wind forecasts.

As utilities replace aging infrastructure and incorporate renewables in remote locations, unlocking extra capacity within existing transmission lines is proving essential. In 2015, the Idaho National Laboratory researched the potential of concurrent cooling—where wind enables wind farms to produce power while also cooling existing transmission lines. The culmination of this work promises to be a more robust and efficient electricity grid.

More than 60% of the U.S. offshore wind resource is located in areas with deep water, where large steel piles or lattice structures fixed to the seabed are not practical. In response, several U.S. companies are developing innovative floating offshore wind platforms for use in deep waters: spar-buoys, tension leg platforms, and semi-submersibles [15].

### 4.1.4 Manufacturing and supply chain

Wind turbine production has become one of the world's largest markets for plastic composites. Fiber-reinforced plastic is critical in the design and manufacturing of wind blades and other turbine components due to their loading requirements, size, and weight. However, the production process is labor-intensive, creating an economic disadvantage.

In 2015, the Institute for Advanced Composites Manufacturing Innovation (IACMI) established its Wind Turbines Technology Area, located in Colorado, and is focused on lowering the cost of wind energy while increasing the reliability of wind turbines. Working with colleges and universities, wind turbine OEMs, turbine component manufacturers, material suppliers, and national laboratories, IACMI is developing advanced composites manufacturing for turbine components including blades, hubs, and nacelles. IACMI's Wind Turbines Technology Area consists of a core partner, NREL, and four supporting partner institutions including Colorado School of Mines; University of Colorado, Boulder; Colorado State University; and Iowa State University.

Capitalizing on the long and productive history of collaboration between NREL and the major wind industry OEMs and suppliers including Vestas, GE, Siemens, TPI Composites, and Johns Manville, IACMI's Wind Turbine Technology Area is developing, testing, and deploying transformational manufacturing methods, designs, and materials that will result in increased penetration for wind power in the U.S. energy market.

A DOE national laboratory Small Business Voucher program was piloted in 2015 to foster strong partnerships between laboratories and high-impact, clean-energy small businesses. Selected projects will receive national laboratory contributions funded directly by DOE as well as access to the expertise, competencies, and infrastructure of the national laboratories.

### 4.1.5 Distributed wind applications

To provide U.S. and global markets with lower-cost, reliable distributed wind systems for onsite power generation, NREL awarded cost-shared grants under the DOE Distributed Wind Competitiveness Improvement Project in 2015. By focusing on component and manufacturing process improvements and turbine testing, the Competitiveness Improvement Project awards help small and midsize wind turbine companies optimize their designs, develop advanced manufacturing processes, and perform turbine testing. Awards went to Intergrid (component improvement), Primus Windpower (certification testing), Ventera Wind (certification testing), Wetzel Engineering (component improvement), and Pika Energy (component improvement). Pika Energy developed a tooling design and cooling process that produces blades using injection-molded plastic, allowing mass manufacturing at a lower cost (less than 50 USD (46 EUR) compared to conventional hand-laid composite blades, which cost more than 1,000 USD (919 EUR) each.

### 4.1.6 Grid system integrations, planning, and operations and stakeholder engagement

In 2015, several U.S. reports were published that focused on grid system integration, planning, and operation. One of the largest regional solar and wind integration studies to date was published in April by NREL and General Electric Energy Consulting. The *Energy Transmission, Storage, and Distribution Infrastructure* report covers the third phase of the Western Wind and Solar Integration Study and explores the integration of large amounts of wind and solar energy into the western electric power system. A second NREL study published in 2015 identified multiple pathways to achieving a 30% penetration of wind and solar in the U.S. Eastern Interconnection—one of the largest power systems in the world. Argonne National Laboratory researchers in 2015 developed a new model to quantify the impacts of variable energy resources on generation expansion and system reliability, discovering that market frameworks can be designed to promote comparable investments in new generation capacity and revenues for existing generators.

### 4.1.7 Workforce development and stakeholder engagement

U.S. workforce development activities in 2015 included release of the DOE Wind Career Map, which shows the broad range of careers and skillsets across the wind industry and highlights paths of advancement among jobs within wind energy sectors. In addition, 12 collegiate teams were selected in 2015 to participate in the U.S. Department of Energy Collegiate Wind Competition 2016 (Figure 2). The competition challenges students to develop a solution to a complex wind energy project, providing them with real-world experience for the wind industry workforce.

In May 2015, DOE issued a Request for Information that solicited feedback from a wide range of stakeholders within the offshore wind community. The purpose of the Request for Information was to gain a better understanding of the value of technology advancement, market barrier removal, and cross-cutting activities.

NREL developed a modeling tool to estimate jobs and other economic impacts associated with offshore wind development in the United States. Researchers worked with industry representatives in four regions of the country to develop geographic-specific offshore wind growth scenarios. Results showed that the offshore wind industry in the United States has the potential to support thousands of jobs—even at relatively conservative levels of deployment and domestic supply chain growth.

### 4.1.8 Siting, radar, and environmental studies

DOE supports efforts to accurately define, measure, and forecast the nation's land-based and offshore wind resources. In 2015, NREL and AWS Truepower released wind resource maps that illustrate the potential for increased U.S. wind deployment. The maps show the concentration of land areas with capacity factors over 35% at higher turbine hub heights of 110 and 140 meters—which could unlock wind power resource potential across more than 1.1 million square miles.

Also in 2015, the Wind Turbine Radar Interference Mitigation Working Group consortium of federal agencies worked to address wind turbine radar interference so that wind development and radar missions can coexist effectively.

Additionally, DOE's numerous federal research activities devoted to wildlife protection included studies assessing the use and technological advancement of ultrasonic acoustic deterrents and other impact minimization technologies aimed at reducing impacts to bats at wind turbines; developing and improving blade strike detection as well as wildlife detection and classification technologies; environmental research grants to reduce the risks to key species and habitats from

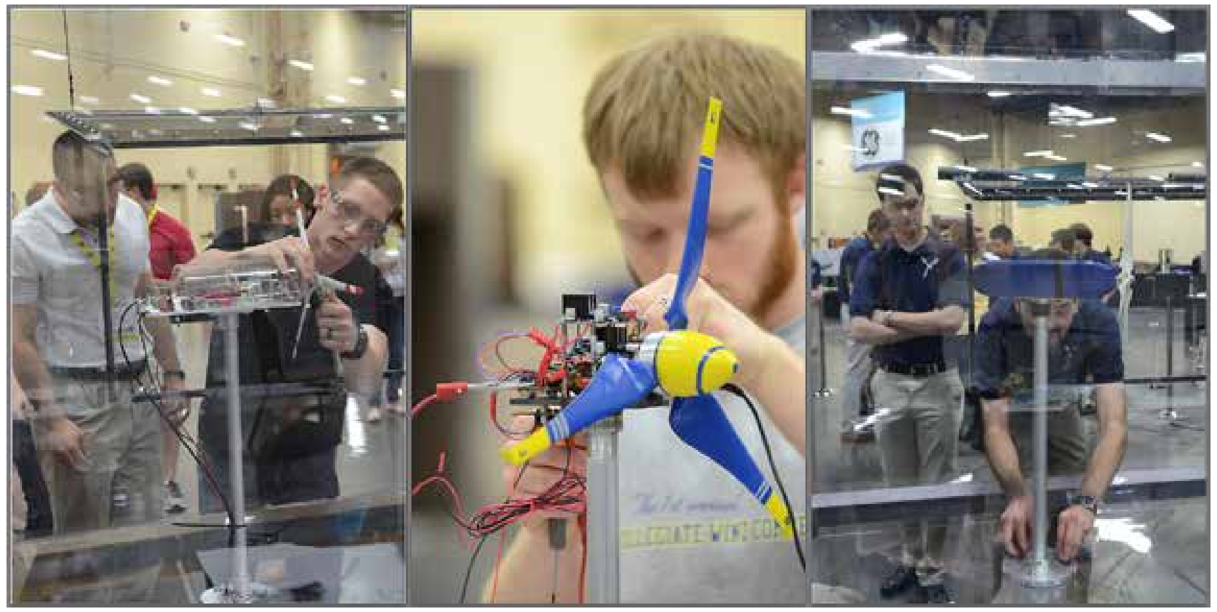

Figure 2. Students participate in the U.S. Department of Energy Collegiate Wind Competition (Photo credit: U.S. Department of Energy)

wind power developments; and research marine life, offshore bird, and bat activity that affects the deployment of U.S. offshore wind projects.

In 2015, DOE continued to lead IEA Wind Task 34's international effort to address the environmental effects of wind energy technology. Also, DOE's Pacific Northwest National Laboratory in 2015 developed an online platform that serves as a central repository for information about the environmental challenges of land-based and offshore wind energy development.

### 4.2 Collaborative research

U.S. wind stakeholders coordinate with many U.S. government departments and agencies through working groups, memoranda of understanding, and other formal and informal relationships as well as engagement with international stakeholders through the IEA, the International Electrotechnical Commission, and other partnerships.

#### 4.2.1 Interagency coordination

Examples of U.S. interagency and international coordination include:

- Radar mitigation: U.S. Department of Defense, the Energy Department, the Federal Aviation Administration, and the National Oceanic and Atmospheric Administration
- Wind plant optimization: Department of Defense, Department of Transportation, Department of the Interior, Federal Aviation Administration and Department of Human Services on radar technical solutions and taller towers and with the National Oceanic and Atmospheric Administration on resource characterization through the Wind Forecast Improvement Project
- Technology transfer: Department of Defense, Department of Interior (Bureau of Ocean Energy Management) on offshore wind permitting and the IEA on codes and standards
- Market barrier mitigation: Department of Interior Bureau of Ocean Energy Management, the U.S. Fish and Wildlife Service, as well as coordination with Department of Defense, Department of Human Services, Department of Transportation (Federal Aviation Administration), and Department of Commerce (National Oceanic and Atmospheric Administration) on wind radar issues
- Advancing grid integration: DOE's Office of Electricity and Federal Energy Regulatory Commission on policy, codes, and standards

#### 4.2.2 International collaborations

DOE supported many research efforts conducted under international collaborations in 2015. These efforts included work with:

- Bats and Wind Energy Cooperative
- Carbon Trust (United Kingdom)
- Det Norske Veritas-Germanischer Lloyd (DNV-GL)
- Technology University of Denmark
- Energy Research Centre of the Netherlands
- European Commission
- Fraunhofer IWES
- International Electrotechnical Commission
- Institute of Electrical and Electronics Engineers
- International Measuring Network of Wind Energy Institutes
- Norwegian Research Centre for Offshore Wind Technology
- Offshore Renewable Energy Catapult (United Kingdom)
- National Renewable Energy Centre (CENER) of Spain
- Technical University of Delft (Netherlands)
- Underwriters Laboratory

U.S. representatives also participated in research conducted for nearly all of the IEA Wind Technology Collaboration Programme (TCP) tasks in 2015 and served as operating agents for Task 26 Cost of Wind Energy, Task 30 Offshore Code Comparison Collaboration Continuation with Correlation Project, Task 31 WAKEBENCH: Benchmarking Wind Farm Flow Models, Task 34 Assessing Environmental Effects and Monitoring Efforts for Offshore and Land-Based Wind Energy Systems, Task 35 Ground-Based Testing for Wind Turbines and Their Components, Task 36 Forecasting for Wind Energy, and Task 37 Wind Energy Systems Engineering: Integrated R, D&D.

Continued involvement in the IEA Wind TCP provides the United States an opportunity to leverage the results of research being conducted by IEA Wind TCP member countries, exchange knowledge and expertise, inform future DOE initiatives, and facilitate technical exchanges with world-class researchers and scientists. For example, the code-to-code and code-to-data comparisons developed in IEA Wind Task 23 and Task 30 projects have helped guide improvements in the U.S. FAST tool, which has benefited U.S. offshore wind companies—such as ABS, Houston Offshore, Principal Power, Glosten, the University of Maine, Alstom/GE, and WindTellect—that use FAST in their design and analysis projects.

## 5.0 The Next Term

According to AWEA, the strong market activity witnessed at the end of 2015 should continue in 2016, thanks to the extension of the PTC supplying the industry with much-needed policy certainty and the more than 9,400 MW of projects under construction at the end of 2015 [13].

DOE's priorities for 2016 include continuation of the Atmosphere to Electrons wind plant optimization initiative and research and development of taller towers and longer blades; three offshore wind demonstration projects—Fishermen's Energy Atlantic City Windfarm, Lake Erie Energy Development Corporation's Icebreaker project, and the University of Maine's New England Aqua Ventus I project; advanced integration studies, including a Pan-North American variable generation and hydropower integration study; an in-depth study of advanced mitigation technologies for eagles and bats; a focus on advanced drivetrain concepts; and continued support for the Collegiate Wind Competition and six Regional Resource Centers across the nation, which provide region-specific information about wind energy to stakeholders and decision makers.

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Opening photo: Red Hills Wind Farm, Elk City, Oklahoma (Photo credit: Todd Spink, NREL 16491)

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ExCo 76 in Rueil-Malmaison, France

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# Appendix C

## Currency Conversion Rates for IEA Wind 2015 Annual Report

| Country | Currency | 1 EUR | 1 USD |
|---|---|---|---|
| Austria | EUR | 1.000 | 1.088 |
| Belgium | EUR | 1.000 | 1.088 |
| Canada | CAD | 0.665 | 0.723 |
| China | CNY | 0.142 | 0.154 |
| Denmark | DKK | 0.134 | 0.146 |
| Finland | EUR | 1.000 | 1.088 |
| France | EUR | 1.000 | 1.088 |
| Germany | EUR | 1.000 | 1.088 |
| Greece | EUR | 1.000 | 1.088 |
| Ireland | EUR | 1.000 | 1.088 |
| Italy | EUR | 1.000 | 1.088 |
| Japan | JPY | 0.0076 | 0.0083 |
| Korea | KRW | 0.00078 | 0.00085 |
| México | MXP | 0.053 | 0.058 |
| Netherlands | EUR | 1.000 | 1.088 |
| Norway | NOK | 0.104 | 0.113 |
| Portugal | EUR | 1.000 | 1.088 |
| Spain | EUR | 1.000 | 1.088 |
| Sweden | SEK | 0.109 | 0.118 |
| Switzerland | CHF | 0.920 | 1.001 |
| United Kingdom | GBP | 1.355 | 1.475 |
| United States | USD | 0.919 | 1.000 |

Source: Federal Reserve Bank of New York (www.x-rates.com)
31 December 2015

# Appendix D

## Abbreviations and Terminology

**availability**: the percentage of time that a wind plant is ready to generate (that is, not out of service for maintenance or repairs)

**balancing cost**: system operating cost increases arising from wind variability and uncertainty

**capacity factor**: a measure of the productivity of a wind plant that is the amount of energy the plant produces over a set time period, divided by the amount of energy that would have been produced if the plant had been running at full capacity during that same time interval. For wind turbines, capacity factor is dependent on the quality of the wind resource, the availability of the machine (reliability) to generate when there is enough wind, the availability of the utility distribution system (no curtailment), and the accuracy of nameplate rating. Most wind power plants operate at a capacity factor of 25% to 40%.

**CCGT**: combined cycle gas turbines

**CCS**: carbon capture and sequestration (or storage)

**CHP**: combined heating and power or cogeneration of heat and power

**CIGRE**: International Council on Large Electric Systems

**CO$_2$e**: carbon dioxide equivalent

**COE**: cost of energy

**CSP**: concentrating solar power

**DFIG**: doubly-fed induction generator

**DSM**: demand side management

**EC**: European Commission

**EIA**: environmental impact assessment

**ENARD**: Electricity Networks Analysis, Research and Development an IEA Implementing Agreement

**EU**: European Union

**ExCo**: Executive Committee (of IEA Wind)

**feed-in tariffs (FIT)**: mandates for utilities to buy the electricity fed into the grid by system owners at a fixed price over the long term. The cost is then redistributed over all electricity customers.

**flicker**: when the operating turbine blades cast shadows on the observer

**full load hours:** the (calculated) amount of time the generators would have run at full capacity to produce the electricity they actually generated in the year. A year has 365 days, hence 8,760 potential full load hours.

**full-time equivalent (FTE)**

**FY**: fiscal year

**GEF**: Global Environment Facility

**GHG**: greenhouse gas

**GIS**: geographical information system

**GL**: Germanischer Lloyd certification body

**GW**: gigawatt (1 billion Watts)

**GWh**: gigawatt hour = 3.6 Terajoules

**h/a**: hours annual

**HAWT**: horizontal axis wind turbine

**hydro**: hydroelectric power

**IEA**: International Energy Agency

**IEC**: International Electro-Technical Commission

**IEEE**: Institute of Electrical and Electronics Engineers

**IPP**: independent power producer

**ISO**: international standards organization

**IT**: information technology

**kW**: kilowatt (one thousand Watts)

**kWh**: kilowatt hour

**LCOE**: levelized cost of electricity; the present value of total costs divided by the present value of energy production over a defined duration

**lidar**: a combined term from "light" and "radar." Uses atmospheric scattering of beams of laser light to measure profiles of the wind at a distance.

**LVRT**: low-voltage ride-through

**m**: meter

**m a.g.**: meters above ground

**m.a.s.l.**: meters above sea level

**MDAO:** Multi-disciplinary design, analysis, and optimization

**Mtoe**: million tonnes of oil equivalent

**MW**: megawatt (one million Watts)

**MWh**: megawatt hour

**m/s**: meters per second

**NA**: not applicable (or not available)

**NGO**: non-governmental organizations

**OA**: operating agent that manages the work of a research task

**OEM**: original equipment manufacturer

**O&M**: operations and maintenance

**penetration rate**: the share of total wind generation relative to total end-use energy demand, expressed as a percentage

**PJ**: peta joule

**PPA**: power purchase agreement

**PSO**: public service obligation

**PV**: photovoltaics or solar electric cells

**R&D**: research and development

**R, D&D**: research, development, and deployment

**RE**: renewable energy

**RES**: renewable energy systems (or sources)

**repowering**: taking down old turbines at a site and installing newer ones with more generating capacity

**RO**: renewables obligation

**rotor**: the blades attached to the hub

**RPS**: renewables portfolio standard

**SCADA**: supervisory control and data acquisition

**semi-offshore projects**: projects in the tidal zone or in very shallow water

**SME**: small- and medium-sized enterprises

**specific power**: the ratio of generator nameplate capacity (in watts) to the rotor-swept area (in m$^2$)

**tCO$_2$-e per capita**: metric tonne of carbon dioxide emissions per person

**TNO**: transmission network operator

**Toe**: metric tonne of oil equivalent

**TSO**: transmission system operators

**TWh**: terawatt hour (one trillion watt hours)

**UN**: United Nations

**UNDP**: United Nations Development Programme

**VAT**: value added tax

**VAWT**: vertical axis wind turbine

**wind index**: the energy in the wind for the year, compared to a normal year.

**wind farm:** also referred to as wind park or wind plant, a group of wind turbines interconnected to a common utility system.

**WT**: wind turbine

**Yr**: year

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**Front cover photo:** Wind turbine in Peuchapatte (Credit: SwissEole)

**Back cover photo:** Wind farm in France (Credit: Maia Eolis)

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