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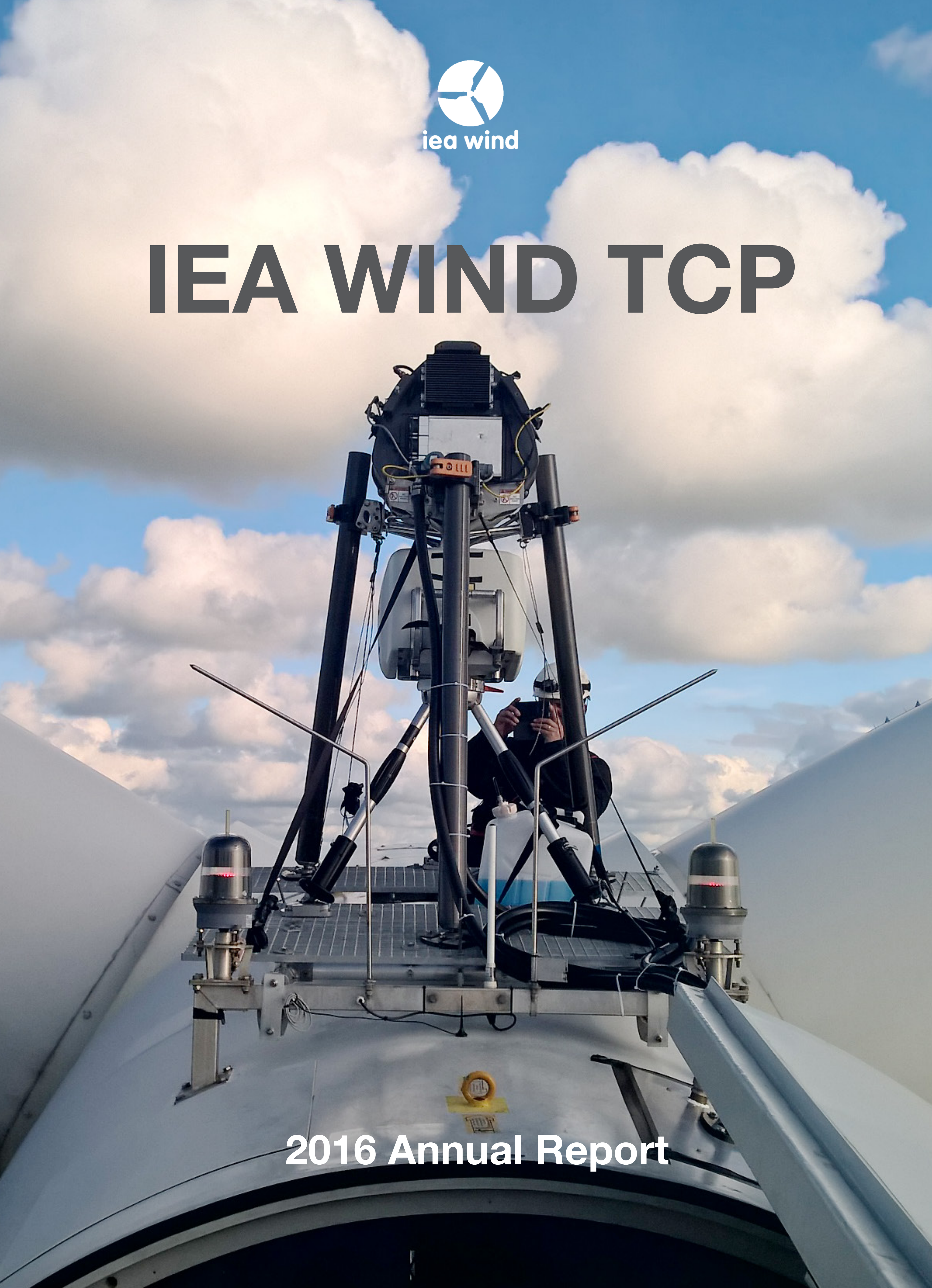

2016 Annual Report


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IEA Wind TCP

2016 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: As part of IEA Wind TCP Task 32 Wind Lidar Systems for Wind Energy Deployment, wind turbine power and loads performance measureed with two nacelle-mounted lidars at Nørrekær Enge in Denmark (Photo credit: Anders Ramsing Vestergaard, DTU Wind Energy UniTTe project, www.UniTTe.dk)

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

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Message From the Chair

In this, my first message as Chair of IEA Wind TCP, I would like to share the vision I had when I started working in wind energy back in 1994. At that time, my main motivation was to help create technology that would make our planet a sustainable place to live. But in those days, no one could foresee the development of wind energy we have today. In 2016, wind energy has beaten several records; to mention a few, the 400-GW mark of installed power has been crossed, Portugal met 100% of its electricity needs at certain times in February and November, and Denmark met an average 38% of its annual electricity demand with wind-generated electricity.

New countries are adopting wind energy as costs keep falling. Recent tenders show that wind energy is becoming the most competitive option in more countries. Wind energy is also opening new opportunities by offering support services to the electricity system. In Spain, for example, 25% of the turbines are providing grid-balancing services. Offshore wind is considered a safe investment by a growing number of investment funds which point to the credibility, performance and reliability achieved. At the same time, offshore wind costs have significantly decreased during the last years.

However, there are challenges that still need to be addressed, such as unstable regulations or lack of wind energy friendly electricity markets. Technology development is still the key to ensuring cost reduction and to enabling an optimal interaction between wind turbines and the energy systems of the future. Research related to upscaling wind turbines could reduce costs further. Research is also needed to facilitate wind energy deployment in new areas with a wider range of environmental conditions. The IEA Wind TCP research Tasks address these challenges by sharing the latest technologies and best practices and by bringing together experts from industry, government, and research institutions from around the world.

The *IEA Wind TCP 2016 Annual Report* documents the development and deployment efforts of our member governments and organizations, as well as the activities and accomplishments of the 15 collaborative research Tasks.

Sustainability remains a key driver for wind energy. Beyond sustainability, however, wind energy has become a competitive, reliable and effective solution to meet the electricity needs of millions across the globe. I am confident that the IEA Wind TCP will continue supporting member countries as they install new wind power capacity, working to overcome barriers to wind power deployment, and developing innovative solutions to support the grid and the environment.

I. Marti

Ignacio Marti
Chair of the Executive Committee, 2016–2017

Contents

Research Task Reports

Country Reports

Appendices

IEA Wind TCP 2016 Overview

Globally, total wind power capacity reached 487 GW at the end of 2016, with 55 GW added during the year. Wind power was the leading source of new power generation capacity in Europe and one of highest sources in the United States and Canada in 2016. The cost of wind energy has steadily decreased over the years, and tender prices in 2016 indicate that wind power is becoming the least expensive option for new power generation capacity in many markets.

The International Energy Agency Wind Technology Collaboration Programme (IEA Wind TCP) is an international co-operation that shares information and research activities to advance wind energy deployment. The IEA Wind TCP is a vehicle for member countries to exchange information on the planning and execution of national, large-scale wind system projects and programs, and to undertake co-operative research and development (R&D) projects called Tasks. In 2016, there were 26 contracting parties to this agreement: 21 member countries, the European Commission, the Chinese Wind Energy Association, and WindEurope, the association for wind energy in Europe (Italy and Norway have two contracting parties).

Nearly 84% of the world's wind generating capacity—and all offshore capacity—resides in the countries participating in the IEA Wind TCP. These countries added about 44 GW of capacity in 2016, making up more than 80% of the worldwide market growth (55 GW). Within the IEA Wind TCP member countries, 410 GW of operational wind power capacity generated almost 800 TWh in 2016 and met 5.2% of the total electrical demand (Table 1).

This 2016 overview of the *IEA Wind TCP 2016 Annual Report* presents highlights and trends from each member country and sponsor member, as well as comparative global statistics. The annual report also presents the latest research results and plans for the 15 co-operative research activities (Tasks), which address specific issues related to wind energy development. Data reported in previous IEA Wind TCP documents (1995–2015) are included as background for discussions of 2016 events. The annual report is freely downloadable at www.ieawind.org.

Progress Towards Policy Targets

Wind energy deployment can help reduce greenhouse gas emissions and other pollutants, increase employment and economic development, contribute to the domestic energy supply, and replace nuclear and coal energy. IEA's *Energy Technology Perspectives 2017* report shows that more than 20% of global electricity should come from wind by 2060 to achieve climate targets [3]. Between 2020 and 2025, offshore wind generation would need to triple and land-based wind power would need to increase 1.7-fold to be on track with a modeled future energy scenario and meet a target of limiting global warming to two degrees Celsius.

The present national targets for renewable energy and wind energy established by IEA Wind TCP member governments are in Table 9, at the end of this chapter.

Record year in many IEA Wind TCP member countries

In 2016, global installed wind power capacity continued to increase in nearly all countries. IEA Wind TCP countries installed 410 GW by the end of 2016, representing 84% of the globally installed capacity (487 GW) (Figure 1) [1, 2]. Wind power was the largest new power capacity installed in Europe (51%). Wind power has overtaken coal as the second greatest source of power generation capacity in the European Union (EU) [1]. Other highlights from 2016 include:

- China was again the largest market, adding 23.4 GW.
- The United States (8.2 GW), Germany (5 GW), and France (1.8 GW) added more than 1 GW each.
- In the United States, total wind power capacity exceeded hydro power capacity.

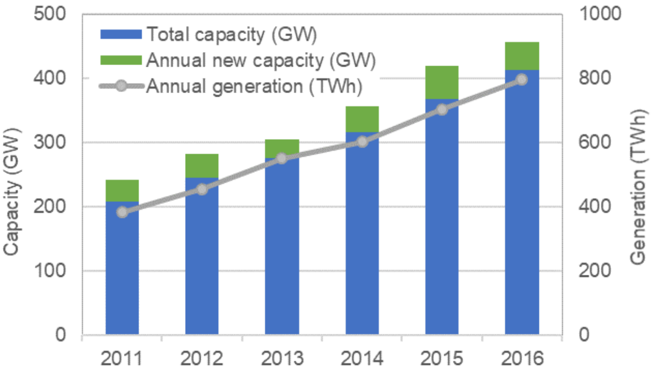

Figure 1. Annual net new and cumulative wind power capacity and electricity production for IEA Wind TCP member countries

- France (1,758 MW), the Netherlands (830 MW), Finland (528 MW), and Ireland (345 MW) surpassed national annual installation records.
- China (615 MW) and the Netherlands (600 MW) set national records in new offshore installations, and the United States installed its first offshore wind power plant (30 MW).

Nine countries added more capacity in 2016 than they had in the previous year. Five countries maintained a similar market, and less new capacity was installed in several larger markets in 2016. Overall, capacity added in 2016 in the IEA Wind TCP member countries was less than added in 2015 (44 GW versus 51.6 GW) (Figure 1 and Table 2). This added capacity amounts to 80% of the 2016 global wind market (54.6 GW) [2].

The largest markets in non-IEA Wind countries were India (3.6 GW), Brazil (2.0 GW), and Turkey (1.4 GW). The largest cumulative capacities in non-IEA Wind countries reside in India (28.7 GW), Brazil (10.7 GW), Turkey (6.0 GW), Poland (5.7 GW), and Australia (4.3 GW) [2].

China, Germany, and the United States lead the world in cumulative and yearly installed capacity. Denmark, Germany, and the Netherlands lead in terms of installed capacity per geographic area (Table 3). In 2016, Finland, the Netherlands, and Switzerland increased their cumulative capacity by more than 20%.

Repowering markets are emerging in Denmark (1.3 GW expected by 2020), Italy, and Spain (where more than 3.5 GW are older than 15 years).

All offshore wind power capacity resides in IEA Wind TCP member countries. The offshore wind sector added 2.1 GW in 2016 for a global total exceeding 14 GW (Figure 2). While close to 90% the total offshore capacity is in Europe, in 2016 only two-thirds of new offshore capacity was installed in Europe. In Belgium, more than 30% of the installed capacity is offshore.

Belgium, China, France, Germany, the Netherlands, the United Kingdom, and the United States have reported plans to build offshore wind power capacity in the coming years. Current floating offshore pilot projects include: Japan (7 MW installed, 5 MW in progress), Portugal (25 MW), and the United Kingdom. France has also received funding for floating offshore projects.

Increasing share of wind power in electricity demand

Wind-generated electricity met approximately 4% of the world's electricity demand in 2016 [1, 2]. In IEA Wind TCP member countries, wind power met 5.2% of electricity demand—an increase over the 4.8% share in 2015. Wind-generated electricity within participating countries increased to 798 TWh (a 13% increase from 2015).

Wind power is playing a major role in meeting electricity demand in an increasing number of countries:

- Seven countries generate more than 10% of electricity demand by wind: Denmark (about 40%); Ireland, Portugal, and Spain (20–24%); Germany, Sweden, and the United Kingdom (11–13%).
- Five states in the United States get more than 20% of their electricity from wind power. The European Union meets more than 10% of its electricity needs by wind power.
- China and the United States generate more than 200 TWh/yr by wind. Germany generates more than 75 TWh/yr. Spain generates close to 50 TWh/yr.
- In 2016, wind energy outperformed coal in the United Kingdom for the first time.
- China, Finland, Greece, and México increased their wind-generated electricity by more than 20% in 2016.

Many countries set records for offshore electricity generation. In Belgium, 44% of wind-generated electricity came from offshore installations (3% of electricity demand). Nearly 37% of wind-generated electricity in Denmark and more than 40% in the United Kingdom was from offshore (almost 14% and over 8% of electricity demand, respectively).

The percent of wind power supplying electricity demand increased in many countries (Austria, China, Finland, Italy, the Netherlands, the United Kingdom, and the United States). Other countries saw wind-generated electricity decrease slightly, due

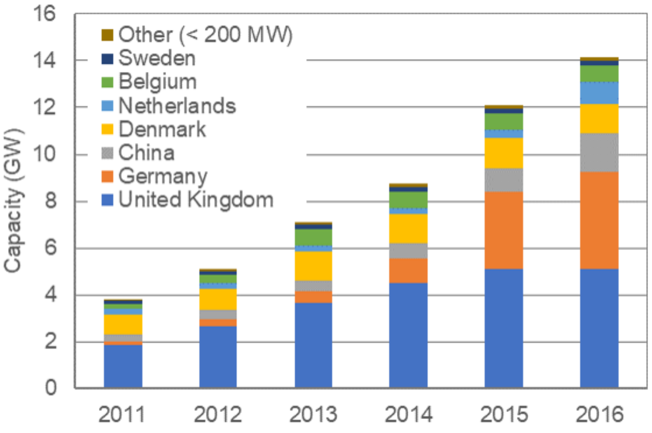

Figure 2. Offshore wind capacity (other includes countries with less than 200 MW offshore capacity installed are Finland, Ireland, Japan, Korea, Norway, Portugal, Spain, United States)

Table 1. Wind Energy Key Statistics 2016

	IEA Wind TCP Member Countries	Global Statistics [1]
Total (net) installed power capacity (land-based and offshore)	413.1 GW	486.8 GW
Total offshore wind power capacity [2]	14.4 GW	14.4 GW
New wind power capacity installed	44.0 GW	54.6 GW
Electrical annual output from wind	793.4 TWh	960 TWh
Wind-generated electricity as a % of electric demand	5.2%	4.0%

Table 2. National Statistics of the IEA Wind Member Countries 2016

Country	Total Installed Wind Power Capacity (GW)	Annual Net Increase in Capacity (MW)	Wind-based Electrical Energy (TWh)	National Demand on Electrical Energy (TWh)	National Electricity Demand Met by Wind Energy (%)
Austria	2.6	228	5.7	60.0	9.5%
Belgium	2.3	84	5.2	80.7	6.2%
Canada	11.9	703	***32.3***	***580.0***	5.6%
China	168.7	23,370	241	5,919.8	4.1%
Denmark	5.2	229	12.8	34.0	37.6%
Finland	1.5	570	3.1	85.0	3.6%
France	12.1	1361	20	***488.0***	4.1%
Germany	49.5	4,993	77.4	594.7	13.0%
Greece	2.4	239	4.8	---	8.4%
Ireland	2.8	345	**6.2**	**29.4**	**20.9%**
Italy	9.3	283	17.5	310.3	5.6%
Japan	3.2	195	5.3	912.2	0.6%
Korea	1.0	115	1.3	561.0	0.2%
México	3.5	454	14.2	298.0	4.8%
Netherlands	4.2	815	8.2	**119.6**	***6.8%***
Norway	0.9	0	2.1	133.1	1.6%
Portugal	5.3	279	12.5	50.8	24.0%
Spain	23.0	38	47.7	247.1	19.3%
Sweden	6.4	605	16.7	136.0	12.3%
Switzerland	0.1	15	0.11	58.2	0.2%
United Kingdom	14.8	938	37.5	338.6	11.1%
United States[1]	82.3	8,205	226.5	4,078.7	5.6%
Totals	**413.1**	**44,021**	**797.6**	**15,122.2**	**5.2%**
Non-IEA Wind TCP countries	**73.8**	**10,441**	**---**		**2%**
World total	**486.9** [1]	**54,462**	**960**		**4%** [2]

Bold italic indicates estimates
[1] includes small wind turbines

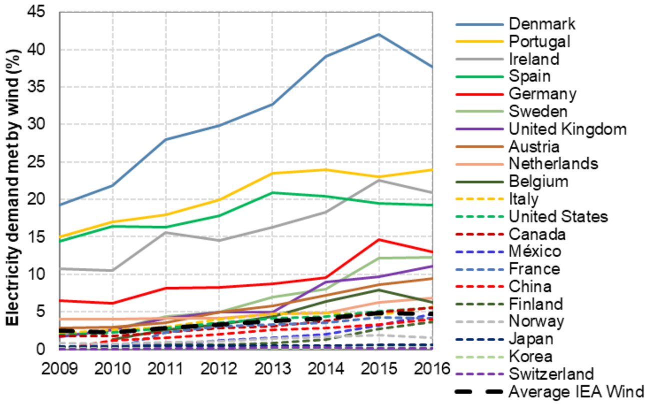

Figure 3. National electricity demand met by wind

to a lower than average wind year (Denmark, Germany, Ireland, and Spain). The world record set by Denmark in 2015 (42% of electricity demand) was not reached in 2016 (Figure 3).

Several countries reported new records of hourly, daily, and monthly shares of wind. In Portugal, wind power exceeded the national consumption on 21 November 2016 from 01:30 until 04:15, with the highest instantaneous share reaching 105%. The maximum daily share of wind, 63%, was also a new record in Portugal. Spain set a monthly record of 30.2% in February 2016, when wind power was the largest source of energy. In Denmark, wind power continued to supply more than electricity demand for more than 100 hours. In the small power system of Ireland, the maximum instantaneous percentage of demand met by wind-generated electricity was 78% in 2016.

Progress towards policy targets and year 2020

IEA Wind TCP member governments establish national targets for renewable energy and wind energy, design market mechanisms and energy policies (Table 5), and fund research and development (R&D) programs to help reach these targets (Table 7). National targets for each member country are listed in Table 9 at the end of this chapter.

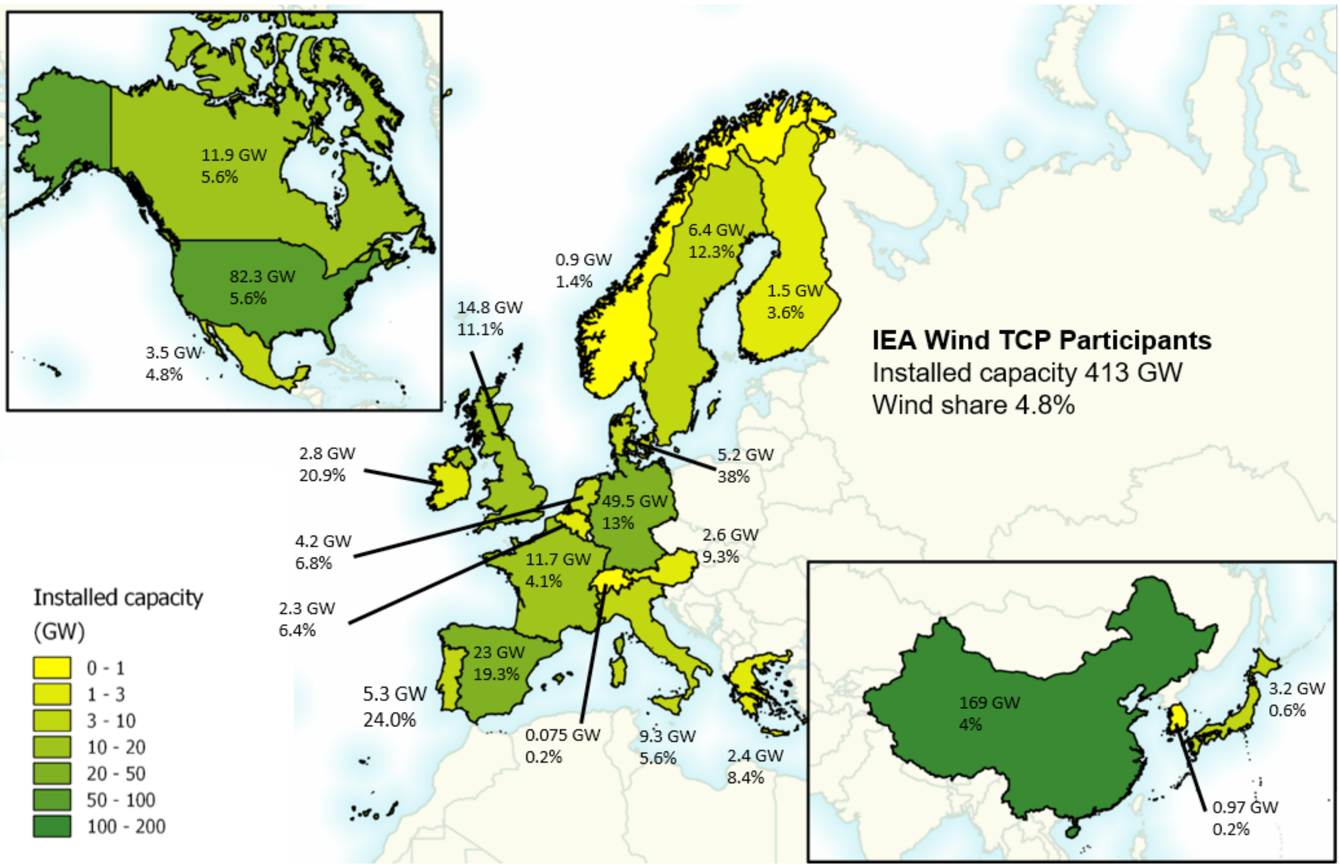

Figure 4. Total installed wind power capacity and wind generated electricity as a percentage of national electric demand in IEA Wind TCP member countries

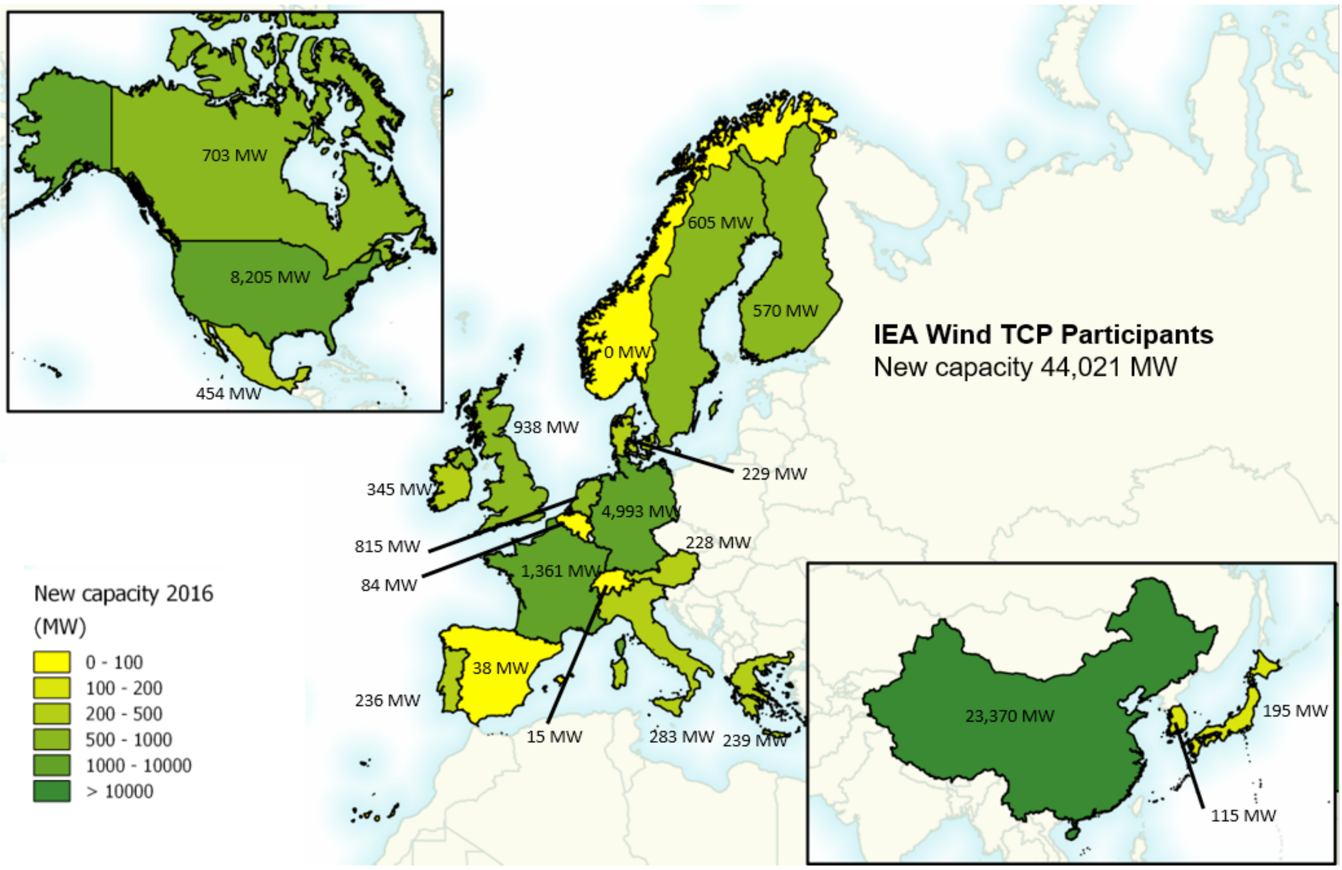

Figure 5. New capacity installed in 2016 in IEA Wind TCP member countries

IEA Wind TCP 2016 Overview

Table 3. Top Ten Wind Power Capacity Rankings: Capacity, % Increase, and Relative to Country Size

	Cumulative Capacity (end of 2016)		Added Capacity (2016)		Increase in Cumulative Capacity (2016)		Cumulative Capacity Relative to Country Size	
	Country	(MW)	Country	(MW)	Country	(%)	Country	kW/km^2
1	China	168,730	China	23,829	Finland	53%	Germany	142
2	United States	82,338	United States	8,205	Switzerland	25%	Netherlands	125
3	Germany	49,534	Germany	4,993	Netherlands	25%	Denmark	124
4	Spain	23,026	France	1,758	France	17%	Belgium	75
5	United Kingdom	14,795	United Kingdom	1,181	China	16%	United Kingdom	61
6	France	12,066	Netherlands	830	Korea	16%	Portugal	58
7	Canada	11,898	Canada	693	Ireland	14%	Spain	46
8	Italy	9,257	Finland	528	México	13%	Ireland	41
9	Sweden	6,422	México	454	United States	11%	Austria	32
10	Portugal	5,313	Sweden	393	Greece	11%	Italy	31

Most countries are progressing towards their established wind energy or renewable energy source (RES) targets (see Table 11 at the end of this chapter for potential installations in 2017). Austria, Finland, and Portugal expect to reach their RES targets before 2020, and Denmark, Germany, Ireland, and Sweden are approaching their targets (Figure 6). The Netherlands auction system for offshore wind—two 350-MW blocks with biannual tendering—is making good progress and decreasing costs, which saves funds allocated for subsidies.

These developments are promising, although other countries are far from achieving their wind energy or RES targets. Belgium, France, and the United Kingdom remain challenged in their progress towards targets. Spain reports that a lack of incentives could keep them from the estimated 6 GW needed to reach their targets.

There were fewer new policy and target announcements in 2016 compared to 2015. Anticipation for future land-based wind policy changes resulted in increased installations in Finland, Germany, and the United Kingdom in 2016. The United States expects steady markets until 2019 when the production tax credit subsidies end. Norway announced that they will be leaving the certificate system after 2021 and reported investment decisions for 1.7 GW of wind power (almost double the amount installed today). Sweden announced a new ambitious target for 100% renewable electricity production by 2040.

Competitive bidding or auctions have become the preferred policy tool to support and deploy large-scale projects for both offshore and land-based wind power. Tendering has been in use for offshore wind power in Denmark and the Netherlands. Germany, México, Spain, and the United Kingdom have already had their first rounds of auctions, and Finland is preparing a technology-neutral auction.

The European Union's RES target (27% of total energy demand) has not been allocated at the country level. The rate of deployment and installation across Europe is uncertain after 2020, because only seven out of the 28 member states have commitments and policies in place beyond 2020. The European Commission's proposed Clean Energy Package is under legislative negotiation and will remain so until at least 2019.

Performance Improvements and Operational Details

Technology increases performance

The trend toward larger wind turbines continued in 2016 (Table 4). Record-sized turbines have been installed in some countries:

- Germany reported a record for the tallest grid-connected wind turbine, which has a hub height of 164 m and a rotor diameter of 131 m (Nordex N131/3300).
- In Denmark, another 8-MW pilot turbine was erected in 2016 (Vestas).
- The average capacity of newly installed land-based turbines exceeded 3 MW in both Canada and Finland.

New technology has led to the development of larger blades and towers and higher power capacities (Figure 7). This has in turn increased the productivity of wind turbines. The current trend is to install larger blades with lower generator ratings, allowing for a decrease in the specific rating. For example, new turbines in the United States average less than 250 W/m^2.

Several IEA Wind TCP Tasks have contributed to the increased wind turbines and component performance:

- **Task 11 Base Technology Exchange** has identified areas of research and development that would benefit from international collaboration and published a series of

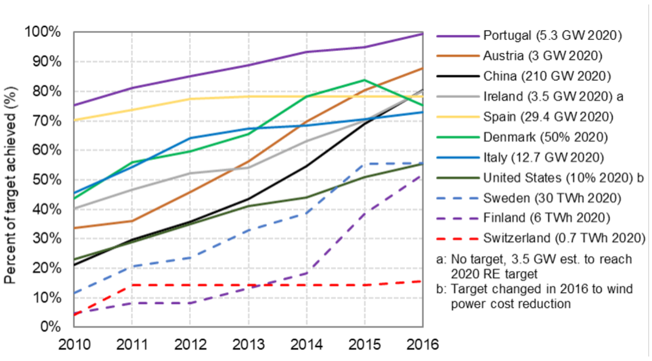

Figure 6. Progress in reaching 2020 wind energy target, percentage of target reached (target in GW, TWh, or share of electricity)

Table 4. Turbine Details 2016

	Total Number of Turbines Operating	Average Capacity of All Turbines (MW)	Average Capacity of New Land-based Turbines (MW)	Average Capacity of New Offshore Turbines (MW)
Austria	1,191	2.2	3.1	---
Belgium	880	---	---	---
Canada	6,288	1.9	3.1	---
China	105,421	1.6	1.9	3.8
Denmark[a]	6,129	1.1	2.9	---
Finland	557	2.8	3.1	3.3
France	5,200	2.3	2.3	---
Germany	28,217	1.8	2.8	5.2
Italy	6,620	1.4	2.1	---
Japan	2,175	1.5	1.9	7.0
Korea	498	1.9	1.7	---
México	2,000	1.8	2.4	---
Netherlands	2,403	1.8	---	4.0
Norway	375	2.3	---	---
Portugal	2,722	1.9	2.0	---
Spain	20,293	1.1	1.1	---
Sweden	3,409	1.9	1.9	2.5
Switzerland	37	2.0	2.9	---
United Kingdom	6,856	2.2	2.2	---
United States	53,343	1.5	2.1	6.0

[a] Average excluding small turbines 25 kW and below.
--- = no data available

Recommended Practices in collaboration with other tasks to reduce the cost of wind energy.

- **Task 19 Wind Energy in Cold Climates** has developed a second edition of Recommended Practices, which can make the development of wind farms in cold climates substantially more affordable and help the wind industry find new solutions and innovations for siting wind power in cold climates.
- **Task 29 Mexnext** is improving aerodynamic modeling, so wind turbine designers can avoid overcompensation for load uncertainties with costly safety measures to avoid risk of instability or failure in high-wind circumstances.
- **Task 30 Offshore Code Comparison Collaboration, Continued, with Correlation (OC5)** is improving offshore wind design tools by training analysts to appropriately use these tools, offshore design processes and public benchmark problems for additional offshore wind research projects focused design, operations and maintenance (O&M), and cost. Improvements to offshore wind industry's engineering tools and methods will allow for more optimized designs.
- **Task 31 WAKEBENCH** is benchmarking different wind and wake modeling techniques to identify and quantify best practices for using these models under a range of conditions, including both land-based and offshore wind, from flat to very complex terrain.
- **Task 32 Lidar** is identifying and mitigating barriers to the use of lidar and is developing Recommended Practices on floating lidar systems, which help reduce cost and improve reliability.
- **Task 33 Reliability** developed a Recommended Practices to help stakeholders in the wind value chain find individually appropriate solutions for wind farm data collection and reliability assessment for O&M optimization.

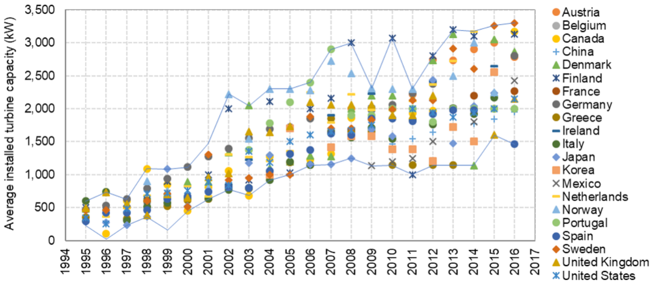

Figure 7. Average capacity of newly installed wind turbines

Table 5. Incentive Programs as of 2016

Incentive Programs		Description	Countries Implementing
Financial incentives	Auctions	Competitive bidding procurement processes for electricity from wind energy or where wind energy technologies are eligible	China, Denmark (offshore), México, Netherlands, Spain
	Feed-in tariff (FIT)	An explicit monetary reward for wind-generated electricity that is paid (usually by the electricity utility) at a guaranteed rate per kilowatt-hour that may be higher than the wholesale electricity rates paid by the utility	Germany, Ireland, Swtizerland, United States
	Variable premium over market price	A variable premium paid is the difference between a guaranteed price and the electricity market price—producers are in the electricity markets	Finland, France, Netherlands
	Fixed premium over the market price	A fixed premium is paid over the electricity market price—producers are in the electricity markets	Canada, China, Ireland, United Kingdom
	Tax relief (income tax credit, relief from import tax or other taxes)	Some or all expenses associated with wind installation may be deducted from taxable income streams; Large wind turbine technologies have imports exempt from customs and import VAT charges	Belgium, China, United States
	Grid connection cost	Offshore grid connection provided by transmission system operator (TSO)	Germany
Market-oriented regulatory incentives	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 (AB, BC, SK, NB, NS), China, Italy, Korea, Norway, United Kingdom, United States (29 states)
	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, Denmark, Ireland, Italy, México, Netherlands, Norway, Sweden, United States
	Electric utility activities like green electricity schemes	Activities include green power schemes, allowing customers to purchase green electricity, wind farms, various wind generation ownership and financing options with select customers, and wind electricity power purchase models	Austria, Denmark, Finland, Ireland, Netherlands, Norway, Sweden, United States
	Commercial bank activities	Includes activities such as preferential home mortgage terms for houses, including wind systems, and preferential green loans for the installation of wind systems.	Korea, Netherlands
	Carbon tax or price on carbon	A tax on carbon that encourages a move to renewables and provides investment dollars for renewable projects	Canada (BC, AB, QC, ON), Denmark, Ireland, Norway
Planning and policy	Investment funds for wind energy	Share offerings in private wind investment funds are provided, plus other schemes that focus on wealth creation and business success using wind energy as a vehicle to achieve these ends	Ireland, Netherlands, United Kingdom
	Spatial planning activities	Areas of national interest that are officially considered for wind energy development	Austria, Belgium, China, Denmark, Finland, Ireland, Korea, Netherlands, United Kingdom, United States (offshore)
	Special licensing to reduce administrative burden	RES plants are exempt from the obligation to attain certain licenses; on islands, RES plants that are combined with water desalination plants get priority	France
Small wind incentives	Net metering or net billing	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 (provinces BC, AB, SK, MB, ON, QC, NB, NS, PE, NL and territories NT, YT), Denmark, Italy, Netherlands, Portugal (microgeneration only), United Kingdom, United States
	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 (ON, SK), Denmark, Finland, Ireland, Italy, United States
	Sustainable building requirements	The requirement for new building developments (residential and commercial) to generate a prescribed portion of their heat and/or electricity needs from onsite renewable sources (e.g., wind, solar, biomass, geothermal); Existing buildings can qualify for financial incentives to retrofit renewable technologies	Ireland, Korea, Portugal, United Kingdom, United States (some cities)

Capacity factors are increasing

Thanks to new technology turbines and increasing shares of offshore wind, many countries are achieving higher average rates of wind-generated electricity. While there has been a trend of increasing capacity factors in previous years, a lower-than-average wind year affected 2016 capacity factors in most IEA Wind TCP member countries (Figure 8).

Except for the United States, no countries reported new capacity records and all reported capacity factors were lower than previous years (Figure 9). In China, curtailments have also affected performance for several years. Offshore capacity factors range between 33.1% and 42.9% in the five biggest EU markets.

Wind power costs are decreasing

New investors worldwide are embracing wind energy as a profitable and growing low-risk sector, and decreasing capital costs have resulted in cost reductions for wind energy tenders. In 2016, some countries saw record low wind tenders. Offshore tendered prices in Denmark decreased to EUR 64/MWh (USD 69.1/MWh) in September and EUR 49.9/MWh (USD 53.9/MWh) in November, and those in the Netherlands reached 72.7 EUR/MWh (76.6 USD/MWh) in June and 54.5 EUR/MWh (57.4 USD/MWh) in December. These costs do not include the grid build-out to offshore sub-stations. The United Kingdom also reported decreasing prices during the year.

Land-based wind power auctions also saw record low prices in México in 2016 (38 EUR/MWh; 40 USD/MWh) and Spain (no subsidy on top of electricity price). These record low costs show an even greater reduction than experts projected in a survey on the future wind energy costs conducted by IEA Wind TCP Task 26 Cost of Wind Energy. Figure 10 shows that the reported cost data from IEA Wind TCP member countries reflect this trend of decreasing investment costs in the last few years (also see Table 10 at the end of this chapter).

IEA Wind TCP Task 26 Cost of Wind Energy convenes experts from around the world to investigate the cost of wind energy technologies and analyze how costs might evolve in the future. The Task has gathered expert perspectives through an expert elicitation to quantify the future cost of energy. Ultimately, the work of Task 26 informs policy and regulatory communities of the current and future cost of wind energy for both land-based and offshore technologies. The Task also seeks to understand how wind technology compares to other generation options within the broader electric sector.

Trend towards operating in electricity markets

Wind power plants are increasingly designed to be operated in the electricity market, such as in Nordic countries, the United Kingdom, the Netherlands, and Spain. Many wind power plants, like those in Austria and Denmark, are eliminating their Feed-in-Tariff schemes, opting to continue with electricity market operation for the rest of the plant's lifetime. This decision implies that wind power plants will cover their imbalance costs by paying fees in the markets.

Electricity markets are being adapted to accept wind-generated electricity, as well as to contract for balancing and system support services. In Spain, 25% of the turbines are enrolling in balancing services. The Task 25 Grid Integration research indicates that flexibility and grid support from wind power plants is an important enabler for integrating higher shares of wind.

Mitigating Deployment Constraints

Members of the IEA Wind TCP work together to tackle deployment constraints. Many countries experience similar growth impediments, and in most cases policy actions will help, or even remove, these barriers. Table 5 provides an overview of some of the measures member countries employ to improve wind energy deployment nationally.

Competing in low-price electricity markets

Considerable reduction in the levelized cost of energy (LCOE) has made wind energy one of the cheapest options for new power generation. However, prevailing low electricity market prices, along with legacy market constructs, present challenges for the transition of wind power to competitive supply. In Europe, there is market overcapacity due to low demand growth and the addition of new renewables. Low fuel prices, as well as low CO_2 market prices related to an excess supply of emission allowances, also exacerbate this issue. Low growth in demand and low fuel prices have been reported as the primary causes of lower prices in Canada and the United States.

In Austria, the collapsed market price and the capped budget for feed-in-tariffs have resulted in a project queue; some projects will be

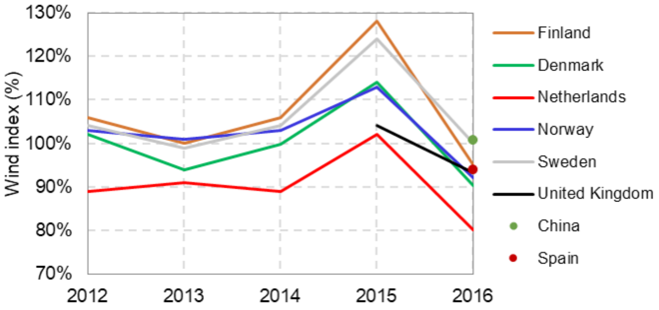

Figure 8. Wind resources reported as wind (production) index

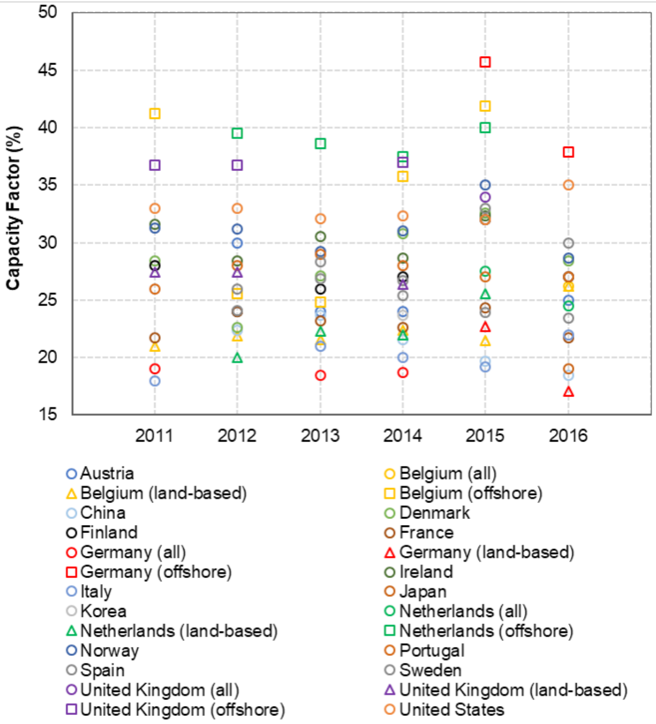

Figure 9. Capacity factors reported (average wind power output); offshore numbers in squares and land-based numbers as triangles, combined in dots

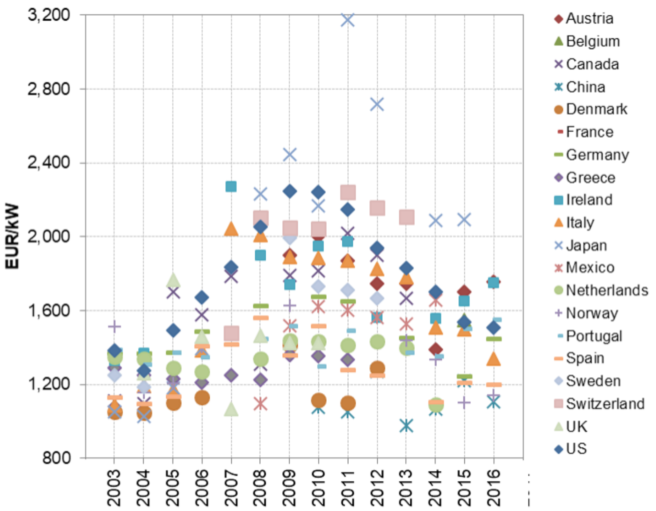

Figure 10. Land-based wind power project cost history from reporting IEA Wind TCP countries

waiting until 2025 to receive new funding. Additionally, high system services cost burdens for wind power producers contributes to lower income and higher risk for operators. Norway foresees that wind power capacity will be built without subsidies after the certificate system ends in 2021.

The lower market prices can create higher demands on financial support mechanisms, as reported in Finland. In Norway and Sweden, green certificate prices have been low, resulting in very low income for wind producers. It will be important to design future markets in a way that allows wind power producers to participate on a level playing field, and allocate any balancing costs for the system in a transparent and cost-effective way.

Reducing wind power curtailment needs

Despite high instantaneous shares of wind power in the electricity system, the system operators in several countries did not report any technical problems in 2016. The system operators in Denmark, Ireland, Portugal, and Spain have shared valuable experience on operating power systems with high shares of variable generation, and they have subsequently prepared their systems to operate with high shares of wind power.

According to IEA Wind TCP Task 25 Grid Integration, curtailment or rejection of available wind-generated electricity is one signal of integration challenges. In the United States (specifically in the state of Texas), curtailment occurs due to the slow pace of adding grid reinforcements.

Curtailment has presented the greatest challenge in China, costing the country 17% of wind-generated electricity (49 TWh) in 2016 (up from 15% and 33 TWh in 2015). The provinces of Gansu (43%), Xinjiang (38%), Jilin (30%), and Inner Mongolia (21%) experience the highest rates of curtailment. Originally, slow construction of transmission capacity and the inability to connect to the grid contributed to this problem. In 2016, curtailment was increasingly due to the operational practices of inflexible coal generation—especially when both electricity and heat are generated in coal-fired power plants. Mitigation methods that are being encouraged include inter-provincial compensation and increasing peak regulation capacity.

In Japan, unlimited curtailment without compensation is becoming an obstacle to wind power development. Electric power companies can curtail renewable energy in Japan. They have forecast that the curtailment might reach 30% in Hokkaido and Tohoku, and 10% in Kyusyu and Shikoku in the future.

Ireland has a small, isolated electricity system in which the contribution of wind-generated electricity exceeded 20% of demand in 2015 and 2016. Even with that high share of wind power, curtailment was less than 3%. The Irish system operator EirGrid is consistently working to achieve a 40% share of renewable electricity, primarily from wind by 2020. To do this, they will take measures to allow the instantaneous system penetration of non-synchronous generation, such as wind to increase from the present record level of 60% up to 75% while keeping wind curtailment moderate.

Improving integration with new transmission capacity

According to reports from IEA Wind TCP Task 25, building more transmission capacity is one of the most effective ways to enable wind integration (Figure 11). The 3,000-MW Chokecherry and Sierra Madre Wind Energy Project in Wyoming—the largest proposed wind farm in North America—aims to deliver its power to utilities in southern California [5]. This will require a new 730-mile transmission line, the TransWest Express Transmission Project, which will run from Wyoming, through Utah, and into southern Nevada. The project will take three years to build at an estimated cost of 3 billion USD (2.85 billion EUR) [5].

México is using tendering processes to build stronger connections from the Tehuantepec Complex to central México by means of a 600-km, high-voltage, direct current line. México

Figure 11. High-voltage direct current transmission (Photo credit: R. Hinrichs)

and the United States are also planning for interconnection of transmission systems. In Canada, a 900-MW transmission project has been proposed to supply clean energy to the northeast United States from New Brunswick.

In Japan, the northern areas (Hokkaido and Tohoku) have good wind resources, but the grid infrastructure is limited due to low population. Tohoku Electric Power Co., Inc., announced in 2016 that new requests for grid connections would be refused in three northern prefectures: Aomori, Iwate and Akita. Hokkaido Electric Power Co., Inc., is required to install large-scale batteries in new wind farm projects after April 2016; the batteries stabilize the fluctuation from wind farm output to the electricity grid.

Increasing focus on public acceptance

Several studies, including a 2016 study in Austria, indicated that wind energy is one of the most preferred energy sources. Despite this fact, social acceptance and questions about the environmental impact of wind energy continue to make project development a challenge in some cases. Key topics vary, from noise and health effects to birds and bats, and countries seek to increase public acceptance and mitigate these challenges in various ways.

- In Canada, 75% of new projects included significant ownership stakes from aboriginal people, bringing economic benefit to their communities.
- In Finland, noise and infrasound issues closed the support system earlier than planned. An impartial study on the health effects of wind power was required, which later became a prerequisite for the new auction-based renewable energy support scheme.
- In Ireland, a "Code of Practice for Wind Energy Development in Ireland" was published to enhance transparency in the community benefit provisions and engage developers with community concerns.

IEA Wind TCP Task 28 focuses on social acceptance of wind energy projects. Key goals include creating knowledge about improving social acceptance, exchanging and producing innovations in social acceptance, identifying the unique challenges of social acceptance for offshore wind energy, recommending regulatory processes and consenting regimes to promote social acceptance, and enhancing the effectiveness of wind energy research to promote social acceptance.

IEA Wind TCP Task 34 Working Together to Resolve the Environmental Effects of Wind Energy (WREN) facilitates deployment of wind energy technology around the globe by promoting better understanding of environmental issues and publicizing solutions for wildlife challenges. The Task published an *Adaptive Management White Paper* as an IEA Wind TCP technical report [1].

Legal and regulatory matters may retard deployment

Many IEA Wind TCP member countries are already streamlining planning and permitting processes. The Norwegian Water and Energy Administration (NVE) is searching for larger sites to enable cost-effective wind deployment. In France, the Energy Transition for Green Growth Act simplified the permitting and licensing process and introduced new measures, including:

- Requiring at least five wind turbines per installation
- Establishing a single authorization process and reducing deadlines for appeals
- Introducing incentives so residents can acquire shareholdings in limited companies involved in local renewable energy projects.

In some countries, the wind energy sector suffers from long permitting and siting procedures. This is due to potentially adverse interactions of wind projects with civil and military aviation, environmental constraints (both land-based and offshore), and burdensome administrative procedures. Legislation changes related to renewable energy can delay deployment, for example:

- Retroactive changes in legislation stopped deployment in Spain and limited wind installations in Finland below the country's original goal.
- In Spain, the 500-MW auction under the new renewable energy support scheme was highly oversubscribed. As a result, some developers with existing wind projects were not able to recoup their costs through the support scheme. Land-based deployment is limited in the United Kingdom, because the auction system only supports offshore projects.
- In Austria, the capped budget for new feed-in-tariff funding, as well as the collapsed market price, has created a project queue that reaches 2025.

In Belgium, spatial planning problems and lengthy legal processes are slowing development. Similarly, in Japan the Environmental Impact Assessment (EIA) process suspended 11 GW of wind development. In Ireland, requests for judicial review of the planning appeals board's final decisions continue to delay the planning processes for many wind farm projects.

Societal Benefits of Wind Energy Deployment

Wind energy benefits society in two major ways: it creates new industries and jobs and achieves environmental benefits by reducing emissions from electricity generation.

Revenue from industries and jobs for people

Wind energy has many environmental benefits, such as CO_2 reduction and other pollutant reduction directly related to health problems in big cities. The wind sector also creates jobs and opportunities on the economic and industrial levels. These benefits come from building and operating wind parks, as well as from building the grid infrastructure and grid connection needed by wind parks. Table 6 shows estimated labor and economic turnover effects of wind energy for 2016 in the reporting IEA Wind TCP member countries.

The wind energy industry expanded globally in 2016, and the IEA Wind TCP member countries reflected this growth in many ways. The United States wind industry had a turnover of 20 billion USD, as more than 500 factories across 43 states built wind turbines and the parts for them. Ohio was the leading U.S. state, with more than 60 wind power-related factories.

European wind turbine manufacturers continue exporting wind turbines outside the EU. As wind technology matures, industry consolidation continued in IEA Wind TCP member countries. In 2016, mergers included Gamesa and Siemens becoming the world's biggest wind turbine OEM, and Acciona Wind Power merging with Nordex. Along the supply chain, GE Wind acquired LM Wind Power and Senvion acquired Euros blade manufacturing. Other interesting

Table 6. Capacity in Relation to Estimated Jobs and Economic Impact 2016

	Cumulative Capacity (MW)	Estimated Number of Jobs	Estimated Economic Impact (million EUR; million USD)
China	168,730	507,000	---
United States	82,338	101,738	18,993; 20,000
Germany	49,534	145,000	11,330; 11,930
Spain	23,026	22,468	2,574; 2,710
Canada	11,898	---	1,060; 1,116
France	12,066	11,000	---
Italy	9,257	26,000	---
Portugal	5,313	3,200	1,338; 1,419
Denmark	5,246	>30,000	---
México	3,527	1,400	---
Ireland	2,800	3,400	---
Austria	2,632	1,490	387; 408
Finland	1,533	4,000-5,000	---
Korea	967	2,424	896; 943
Switzerland	75	---	37; 39
Total		**>850,000**	**>36,000; 38,500**

collaborations across industries included Nordex and Lufthansa Aerial's service collaboration in rotor blade inspection and Enercon's collaboration with the utility EWE, developing new business around renewable energies and smart grids.

Corporate Power Purchase Agreements (PPAs), or long-term contracts between renewable energy developers and corporations to purchase the generated energy, are becoming a new market driver for wind energy. In 2016, more than half of the turbines in Europe were sold directly to power producers or utilities, and the remaining ordered turbines were sold to developers or private investors. According to *GWEC Global Wind Report 2016*, corporations in the United States signed orders for 1,574 MW (39% of the capacity contracted through PPAs) during the year. Of the 8,203 MW installed in 2016, 24% had a PPA with a corporate buyer [1].

Many countries cited the number of workers employed in the wind energy sector as a key benefit of wind energy. Employment in the wind sector increased in 2016 over 2015 in all main markets: China, North America, and Europe. More than 850,000 estimated full-time equivalent jobs related to the wind energy sector were reported by IEA Wind TCP member countries for 2016 (Table 6).

- China estimates that the number of jobs will grow from 500,000 to about 800,000 by 2020.
- The United States wind industry offers more than 100,000 jobs, which is more than coal, natural gas, nuclear, or hydroelectric power plants.
- Canada made regional evaluations of job creation in 2016. Ontario's wind procurement program will generate 41,500 direct and indirect full-time jobs from 2013 to 2019. Quebec's wind industry supports an estimated 5,000 jobs per year.
- In the EU, the wind industry employs more than 330,000 people, with about 145,000 in Germany, and 20,000–30,000 jobs each in Denmark, Italy, and Spain.

More environmental benefit and smaller footprint

Many IEA Wind TCP member countries have calculated the avoided CO_2 emissions (million tons/year) attributable to wind energy, including Germany (52.5), Spain (11.5), Italy (9.7), Portugal (4.3), Ireland (2.2), and Finland (2.1). These calculations are based on the national generation mix and usage patterns of each country.

China predicts that wind power will save 150 million tons of standard coal per year and reduce 380 million tons of CO_2, 1.3 million tons of sulphur dioxide (SO_2), and 1.1 million tons of nitrogen oxides (NO_x) in 2020. Wind energy will play an important role in reducing air pollution and controlling greenhouse gas emissions.

In the 28 member states of the EU, the avoided greenhouse gas emissions due to the deployment of wind energy reach between 400 and 550 Mt, depending on the assumptions used. Cumulative avoided CO_2 emissions range between 8,700 Mt and about 13,000 Mt for the period 2015–2050. This is approximately 2.5 to 3.5 times the current annual CO_2 emissions from the EU energy sector.

México estimates that developing 12,000 MW of wind power by 2020 would help reduce emissions by more than 20 Mt of CO_2 by 2020—approximately 10% of the national mitigation target.

In the United States, wind energy greatly reduces a variety of air pollutants, including smog-causing SO_2 and NO_x. This helps lower the rate of asthma and other respiratory health issues. U.S. wind generation in 2016 displaced an estimated 178,000 metric tons of SO_2 and 110,000 metric tons of NO_x, representing $8.67 billion USD (8.24 billion EUR) in avoided health-care costs. It also reduced water consumption at existing power plants by about 86.7 billion gallons.

In Denmark, the environmental benefits due to the 2016 wind energy production have been calculated, assuming coal is being substituted. Wind energy saved 4.2 million tons of coal (332 g/kWh), reduced 9.9 million tons of CO_2 (772 g/kWh), reduced 893 tons of SO_2 (0.07 g/kWh) reduced 2.3 thousand tons of NO_x (0.18 g/kWh), reduced 255 tons of particles (0.02 g/kWh), and reduced 667 thousand tons of cinder and ash (52.3 g/kWh). Belgium has reported positive environmental impacts from offshore deployment, increasing biodiversity on the support structures.

In 2016, Ireland published a free Environmental Sensitivity Mapping (ESM) webtool for strategic environmental assessment for screening of infrastructure projects, including wind farms. Technical development to reduce the footprint of wind power projects took place in 2016, including tower and construction concepts for large wind turbines (over 3 MW) that avoid the use of high capacity cranes:

- In the Netherlands, Lagerwey developed and demonstrated a steel tower concept with a self-climbing crane.
- France developed pre-stressed wind turbine concrete towers, which incorporate lifting equipment.

Value of Research, Development, and Innovation

National priorities and public R&D funding

Research, development, and innovation priorities in IEA Wind TCP member countries are shaped by the national, regional, social, political, and energy circumstances. The level of public funding varies substantially. Several countries invest heavily to promote wind energy (Germany, Japan, and Spain), while other countries disperse their R&D funding with a mix of public and private investments (Italy). It is difficult to calculate the total research investments supporting wind energy technology in many countries. Table 7 shows the national budgets, public-funded research, development, and innovation into wind energy systems for several member countries.

In many countries, one national body coordinates all wind-energy R&D and represents the R&D community and the industrial sector. This includes organizations such as the Swedish Wind Power Technology Centre, the Méxican Centre for Innovation in Wind Energy (CEMIE-Eólico), the Topconsortia for Knowledge and Innovation (TKI Wind Offshore Wind) in the Netherlands, and the Finnish Wind Power Research Network (FinWindResearch)—a network of wind power experts established in 2016 to support information exchange, cooperation, and new innovations.

Offshore wind R&D is active in many countries. The United Kingdom's R&D efforts aim to reduce costs, enabling offshore wind power to be competitive against conventional forms by the mid-2020s. In Germany, projects focus on offshore logistics with cost-effective transport solutions and modularized components. The United States is investing in the development and demonstration of offshore wind technologies and refining domestic wind industry manufacturing technology. China's research focuses on key technology and equipment development for offshore wind turbine tests.

In the Netherlands, wind energy R&D programs focus solely on offshore wind. Similarly, offshore wind and large wind turbine technology have been a priority for France in recent years. The Norwegian R&D program focuses on both seabed-based and floating offshore wind, covering the full value chain from foundations and offshore assembly, to grid connection and robust operation and maintenance.

Floating offshore wind systems are an important R&D topic in many IEA Wind TCP member countries because of the potential to install very large turbines in deep waters. France has four ongoing demonstration projects on the Mediterranean and Atlantic coasts. In Spain, offshore wind R&D activities are increasing, especially for floating components. In Italy, research is underway on turbines up to 20 MW and on floating substructures, as part of several EU projects under the Seventh Framework Programme (FP7) and Horizon 2020. Japan is also conducting several research and demonstration projects on floating offshore wind power.

IEA Wind TCP Task 30 (OC5) focuses on offshore wind structures and is working to validate and improve offshore wind modeling tools by comparing simulated and actual measurements (Figure 12). The project combines efforts of 13 participating countries and brings together experts from both the offshore structure and wind energy communities including designers, consultants, certifiers, developers, and research institutions.

Austria's R&D activities support **cold climate wind** installations, including areas such as ice mapping, ice throw, and safety. Cold climate wind is also a priority in Finland, where research focuses on sensor development and testing procedures, and on product development for blade heating systems. Sweden and Norway are funding research on icing issues in wind power production. The Swiss R&D program is focused on innovative turbine components for specific application in harsh climates, which may increase the availability and energy yield at extreme sites. China and Canada are also funding R&D projects in this area. Many of these activities contribute to IEA Wind TCP Task 19 Wind Energy in Cold Climates.

The installation and operation of small wind systems in urban, highly turbulent areas is an R&D priority for Austria, China, Denmark, Ireland, South Korea, Japan, and Spain. Spain funds projects to demonstrate the integration of wind energy in both grid-tied and remote off-grid applications. In Ireland, development of smaller, cost-effective systems that are suitable for community-based sustainable energy initiatives is a key R&D priority. Based on the Field Test Program data from the Sustainable Energy Authority of Ireland (SEAI), a study is being conducted to understand the impact of micro-siting on electricity production and new methods are being developed to better estimate electricity production for a specific site. China is conducting numerical simulations of flow fields around buildings. Denmark refined the software tool WaSP for small wind turbines by using fence experiment measurements to understand what happens to the flow around a blockage to the wind.

IEA Wind TCP Task 27 Small Wind is continuing research, analyses, and measurements to further refine areas within the IEC 61400-2 standard on the safety, integrity, and design requirements of small wind turbines. The results of this work will be considered by future IEC 61400-2 Maintenance Team 2 experts who will work to produce the fourth revision of the standard.

Turbine technology advancements have the potential to increase yields, decrease costs, and extend equipment lifespans. In Spain, extension-of-life strategies are important, as are developing optimized manufacturing processes (e.g., for towers). The United States is working towards competitiveness by applying advanced manufacturing techniques to wind turbine components and tooling; one example is the use of three-dimensional printing to manufacture wind turbine blade moulds. In China, quality evaluation of production processes for wind technology is a key R&D focus. Denmark published important strategy papers in 2016, including *Test and Demonstration Facilities for Wind Energy Needed to Promote a Competitive Wind Industry in Denmark* and *Strategy for Extending Useful Lifetime of a Wind Turbine*, a report on

Figure 12. Offshore wind system examined in IEA Wind TCP Task 30 OC5 Phase III: Jacket – Open Ocean Test (Photo Credit: Gary Norton, NREL)

Table 7. National R&D Budgets for Reporting Countries, 2010–2016

Country	National R&D Budget in million EUR; (million USD)						
	2010[a]	2011[a]	2012[a]	2013[a]	2014	2015	2016
Belgium	---	---	---	---	---	4.36; (4.74)	---
Canada	---	6.00; (7.76)	4.23; (5.84)	3.62; (4.99)	***3.89; (4.71)***	2.15; (2.34)	3.2 (3.4)
China	---	---	---	---	---	10.75; (11.7)	1.4 (1.44)
Denmark[b]	18.0; (24.2)	0.77; (1.0)	8.7; (11.5)	17.6; (24.2)	18.0; (22.0)	14.3; (15.7)	14.6 (15.4)
European Commission	34.97; (47)	27.31; (36.71)	61.35; (80.94)	65.67; (90.46)	24.71; (29.92)	289.5; (315)	65.1 (68.5)
Finland	4.00; (5.2)	10.00; (12.9)	2.00; (2.75)	3.12; (4.3)	0.99; (1.2)	1.7 (1.85)	1.7 (1.85)
Germany	52.96; (71.18)	81.21; (105.09)	78.31; (103.21)	36.75; (50.64)	38.51; (46.64)	91.10; (99.12)	88.7 (93.37)
Ireland	0.30; (0.4)	0.30; (0.4)	0.88; (1.07)	---	---	---	---
Italy	3.00; (3.96)	3.00; (3.96)	3.00; (3.89)	3.00; (4.13)	3.00; (3.63)	2.48; (2.7)	---
Japan	18.29; (24.58)	31.92; (42.91)	41.89; (55.26)	25.05; (47.5)	52.73; (63.84)	117.60; (127.94)	68.63 (72.24)
Korea	28.36; (38.12)	29.10; (37.66)	33.91; (44.69)	35.60; (49.06)	---	---	28.50 (30)
México[c]	---	---	---	---	2.10; (2.50)	3.48; (4.36)	2.21; (2.31)
Netherlands	38.00; (51.07)	7.08; (9.15)	8.10; (11.6)	5.07; (7)	3.73; (4.51)	---	---
Norway	12.60; -16.72	14.87; (19.69)	17.14; (22.68)	13.20; (18.19)	12.39; (15)	9.38; (10.2)	10.26 (10.8)
Spain	150.00; (115.91)	150.00; (115.91)	120.00; (158.16)	85.50; (117.82)	---	86.40; (94)	81.23 (85.5)
Sweden	10.80; (14.47)	10.80; (14.47)	10.80; (14.23)	10.80; (14.88)	6.45; (7.81)	7.08; (7.7)	7.32 (7.7)
Switzerland	0.41; (0.53)	0.41; (0.53)	0.41; (0.53)	0.41; (0.53)	0.39; (0.47)	0.51; (0.55)	0.62 (0.653)
United States	75.1; (79)	74.9; (78.8)	87.2; (91.8)	81.8; (86.1)	82.7; (87)	101.7; (107)	90.7; (95.5)

--- indicates no data available

[a] Currency is expressed in year of budget. It is not adjusted to present value

[b] Projects supported by public funds

[c] Sectorial Fund CONACYT-SENER-Energy Sustainability (FSE) budget, does not include concurrence from the members of the CEMIE-Eólico

technological solutions to reduce the environmental impacts of wind-energy systems.

Innovative concepts for wind turbines are being developed in many countries. México and Germany fund smart blade projects.Innovative control systems for turbines and wind farms are important research topics as well. Germany is developing innovative control systems to modify blade profiles. Italy has studied kite-based wind generation using a 3-MW kite wind generator and Spain is using flight simulations and traction kite testing. In the United Kingdom, multirotor systems are being evaluated and Denmark has installed and is testing a new multirotor concept.

Most IEA Wind TCP member countries are focusing on **integrating wind energy into power systems**. IEA Wind TCP Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power provides information to facilitate the highest economically feasible wind energy penetration in electricity power systems worldwide. Switzerland and Portugal are funding research to maximize the penetration of renewable energy, from both a grid security operation point of view and a market perspective.

Belgium is working on integration services for large amounts of wind energy. IEA Wind TCP Task 36 Forecasting for Wind Energy is working to improve the accuracy of forecast models and their utility to the wind industry.

Operation and maintenance issues are an R&D focus for México (increase the reliability and availability of wind turbines and wind farms), Spain (find cost-competitive O&M solutions), and China (condition monitoring technologies for early damage detection and operation reporting).

IEA Wind TCP Task 33 Standardization of Data Collection for Wind Turbine Reliability and Operation & Maintenance Analyses focused on data collection from Supervisory Control and Data Automation (SCADA) systems, maintenance activities, and reliability issues. The Task has worked to identify operators' demands, proposed the most appropriate statistical methods for providing key figures, and suggested which data to collect. Task 33 concluded at the end of 2016 with the resulting *Wind Farm Data Collection and Reliability Assessment for O&M Optimization*.

Remote sensing for **resource assessment** is an R&D topic in countries such as Germany, Norway, and Spain (Figure 13). Japan is developing a floating offshore wind measurement system consisting of Doppler lidar with inclination compensation and measurements for motion of the floating unit and waves. China is also testing various lidar systems.

Finland, Germany, and the United States are studying issues related to **environmental impacts** of wind energy, particularly regarding birds and bats (Figure 14). Additionally, **social acceptance** is an important R&D issue for nearly every country. Swedish knowledge program Vindval is focused on studying the environmental effects of wind power.

R&D paves way for cost-competitive energy

Throughout 2016, each of the IEA Wind TCP member countries worked on wind energy R&D. Their research is highlighted in their respective country chapters, but some key highlights are listed below:

The Pan-Canadian Wind Integration Study, released by the Canadian Wind Energy Association (CanWEA), found no operational barriers to achieving 35% wind penetration in Canada by 2025. The study also found that increased wind energy deployment could reduce 32.3 million tons of CO_2 equivalents in Canada and generate new revenue via electricity exports to the United States.

In Denmark, research in 2016 addressed new wind scanner developments. This research explores the interaction between the wind and a turbine rotor. This knowledge will help develop and refine the computer models used to simulate load and control, thus optimizing the turbine design.

México streamlined the development of small wind turbines through the design, construction, and testing of a 30-kW wind turbine. México also developed a blade-manufacturing laboratory for small wind turbines, which includes blade design, blade manufacturing engineering, mould and tooling making, and blade making.

Portugal completed the demonstration phase of the WindFloat prototype at Aguçadoura in the summer of 2016. This concept structure proved to be a technically viable solution for floating deep offshore wind plants. The first floating offshore wind park based on WindFloat technology is expected to be installed in 2017.

In 2016, the Swiss Ornithological Institute conducted research at a wind park known as a high bird migration site. Their research resulted in 20 carcasses (no sensitive species) from wind farm collisions—approximately 100 times fewer than initially predicted. According to these findings, there is no correlation between collision events at the height of the wind turbines and migration intensity. Swiss Ornithological Institute's research confirms the results of other international studies, which assert that migration intensity through wind farms is not a relevant issue in bird mortality. The practice of shutting down turbines during bird migration should be reconsidered, because it would reduce energy production and have a limited effect on bird mortality.

The United States deployed a lidar buoy off Virginia Beach. The buoy contained high-tech instruments to measure wind speed at multiple heights, air and sea-surface temperature, barometric pressure, relative humidity, wave height and period, and water conductivity. The buoy yielded useful information about data quality and revealed that the United States experiences more low-level wind jets than European offshore environments.

The U.S. National Renewable Energy Laboratory (NREL) released its latest version of the FAST modeling program (FAST v8): an open-source, multiphysics engineering software tool used to design and analyze wind turbines. The University of Strathclyde in the United Kingdom is developing a new 20-MW machine

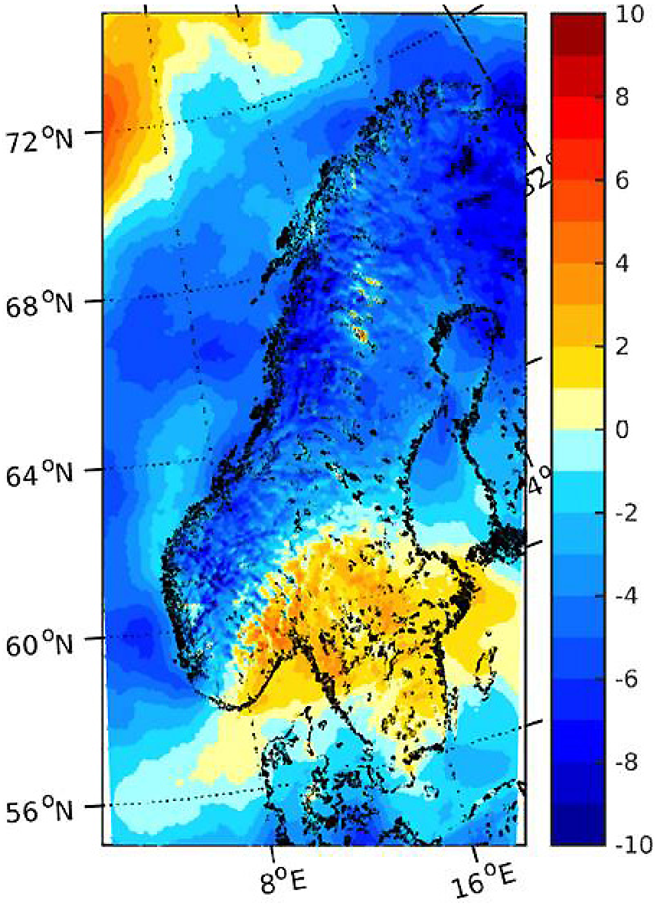

Figure 13. Wind index over Scandinavia in 2016. The scale is in percent departure from normal for the mean wind speed. The blue shows that it was a bad wind year over most of Scandinavia. (Photo credit: Kjeller Vindteknikk)

Table 8. Examples of Test and Demonstration Facilities in IEA Wind TCP Member Countries

Application Area	Country	Facility Description
Offshore wind demonstrations	Finland	New construction of a 42-MW offshore wind demonstration in seas prone to icing
	France	• Demonstration projects: Faraman: with three Siemens 8-MW wind turbines in the Mediterranean Sea • Groix-and Belle- Ile: four GE Haliade 6-MW turbines on the Atlantic Coast • EoldMed: four Senvion 6.15-MW turbines in the Mediterranean Sea near Gruissan • Leucate: three GE Haliade 6-MW turbines in the Mediterranean Sea
	Japan	METI Floating Offshore Wind Farm Demonstration Project (Fukushima FORWARD PJ) with a 2-MW and 5-MW Hitachi downwind type wind turbine and a MHI 7-MW wind turbine
	Portugal	Demonstration phase of WindFloat completed successfully
	Spain	• PLOCAN, a permanent deep-sea observatory, a test-bed for innovative technologies • BISCAY Marine Energy Platform S.A. (BIMEP), a public infrastructure for research and testing in the field of the marine energies
	United Kingdom	• Upgraded the Wave Hub demonstration site and continued developing floating wind parks Hywind Scotland, Kincardine Offshore Windfarm and Dounreay Trì
Land-based test and demonstration sites	Canada	• TechnoCentre éolien is a center of expertise for wind energy R,D&D focusing on wind farm performance optimization and renewable energy integration in Gaspé, Quebec • The Wind Energy Institute of Canada, located in Prince Edward Island, features a 10-MW wind R&D park, an energy storage test bed, and other test systems that provide opportunities to research, demonstrate, test, and validate technologies in a real world setting
	Denmark	Test sites at DTU Risø Campus, Roskilde, Høvsøre Test Site for Large Wind Turbines at Lemvig, and Test Center Østerild at Thisted
	Germany	• Test Field Bremerhaven provides a next-generation wind turbine as a research platform for free-field measurements • German Research Platform for Wind Energy (DF Wind) includes two multi-MW wind turbines (2.5–3.5 MW), one 500-kW experimental turbine, four meteorological masts (100–150 m), and additional R&D infrastructure • Wind Science and Engineering Test Site (WINSENT) in Baden Wurtenberg has two 750-kW experimental turbines, four 100-m meteorological masts, and additional R&D infrastructure
	Sweden	Planning cold climate test site
	United Kingdom	Fully operational and accessible wind turbine for use for R&D at Levenmouth
	United States	• National Wind Technology Center is a center of expertise for wind energy RD&T, including test turbines, blade and drivetrain test beds, and a controllable grid interface • 90-meter blade testing in Massachusetts • 7.5-MW drivetrain testing in South Carolina
Ground testing of components	Belgium	Set up industrial innovation platform
	Denmark	Constructing a new facility for advanced structural and materials testing
	Germany	DyNaLab nacelle test bench
Cold climate test laboratories	Belgium	Icing wind tunnel and low temperature test chamber
	Denmark	Icing wind tunnel
	Finland	Two icing wind tunnels for instrument and material research and testing in icing conditions
Wind resource assessment	Belgium	Floating lidar (FLiDAR) and offshore measurement systems
	United States	Wind Forecast Improvement Project, three new radar wind profilers—one every 150 miles—along the coast of Oregon and Washington

More comprehensive data on test facilities can be found e.g. in the US DOE's *Wind Energy Facilities Book* [5] and at *Catalogue of Facilities Available*, published by EU FP7-project IRPWIND (www.irpwind.eu/publications/deliverable)

Figure 14. Spirit, a 20-year-old bald eagle outfitted with a global positioning system logger, assisted with the collection of eagle flight pattern data for two different technology solutions under development that could ultimately be used at wind energy facilities to prevent eagle collisions with wind turbines. One solution in-cludes radar; the other is a visual system. The research was a collaboration between the National Wind Technology Center at the National Renewable Energy Laboratory and others, including a wind industry company, a technology developer, and academia. (Photo credit: Lee Jay Fingersh, NREL)

consisting of 45 444-kW rotors. This multi-rotor-technology is expected to reduce the LCOE by 30%.

Test facilities and demonstration projects support innovation

Several countries began operations at or construction on new facilities and demonstration projects in 2016. These projects should meet the greater variety and volume of needs within the research infrastructure. Table 8 highlights several of the test and demonstration facilities in IEA Wind TCP member countries.

Collaborative research leverages national efforts

The research, development, and innovation priorities of the EU include basic and applied research and demonstration projects, which span the spectrum of elements necessary to reduce the cost of wind energy. Platforms, initiatives, and collaborations join research efforts among countries. EU research, development, and innovation priorities specifically include:

- 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

Nordic Energy Research is the platform for cooperative energy research and policy development under the Nordic Council of Ministers—the intergovernmental body between Denmark, Finland, Iceland, Norway, and Sweden [6].

The North Seas Countries' Offshore Grid Initiative (NSCOGI) is a collaboration program signed by nine countries (Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, and Sweden) and the EU. It is an initiative for the development of offshore wind energy, ensuring a sustainable, secure, and affordable energy supply in the North Seas countries. This initiative will facilitate the building of missing electricity links, allow for more energy trade, and further integrate energy markets. Through regional cooperation, the North Seas countries will help reduce greenhouse gas emissions and protect the energy supply in the region.

The IEA Wind TCP research portfolio defined by the countries participating in the ExCo is enabling knowledge transfer and effective collaborative research that produced key outputs like recommended practices and technical reports widely used by industry and the public sector worldwide.

References:

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[3] IEA (2017). *Energy Technology Perspectives 2017*. Download from: http://www.iea.org/etp2017/

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[5] U.S. DOE (2017) *Wind Energy Facilities Book*. Download from: https://energy.gov/eere/wind/downloads/us-department-energy-wind-energy-facilities-book

[6]Nordic Energy Research. www.nordicenergy.org

Authors: Hannele Holttinen, Esa Peltola, and Simo Rissanen, VTT Technical Research Centre of Finland, Finland.

Table 9. Targets Reported for IEA Wind TCP Member Countries

	Official Target Renewable Energy Sources (RES)	Official Target Wind (2016)	2016 Total Wind Capacity (MW), Annual Contribution to demand (%), or Annual Production (TWh)
Austria	34% RES share of gross domestic consumption	3,000 MW by 2020	2,632 MW
Belgium	13% RES share in final gross energy consumption by 2020	2,741 MW offshore wind: and 3,000 MW land-based by 2020	2,260 MW
China	680 GW by 2020	210 GW by 2020	169 GW
Denmark	30% by 2020, 50% by 2030; independent of fossil fuels by 2050	50% by 2020	37.6%
European Union	20% of energy demand by 2020; 1,206 TWh of renewable energy electricity by 2020	486 TWh by 2020	---
Finland	39% by 2020	6-6.5 TWh/yr by 2020	3.1 TWh
France	---	Land-based: 15 GW by 2018 Offshore: 0.5 GW by 2018	---
Germany	Gross energy demand: 30% by 2030, 45% by 2040, 60% by 2050; gross electricity demand: 40-45% by 2025, 55-60% by 2035, >80% by 2050	Land-based: 2.8 GW/yr 2017-2019; 2.9 GW/yr from 2020 on; Offshore: 15 GW by 2030 (500 MW/yr 2021-2022, 700 MW/yr 2023-2025, 840 MW/yr from 2026 on)	49,534 MW
Ireland	16% of total energy demand by 2020, projected 40% of electricity demand	---	---
Italy	17% by 2020	12 GW land-based and 0.68 GW offshore by 2020	9,257 MW
Japan	21-23% by 2030 per the 4th Strategic Energy Plan (METI 2014)	10 GW by 2030 per Long-term Energy Supply and Demand Outlook (METI 2015)	3,234 MW
Korea	0.03	0.9% by 2020	0.24%
México	---	12.8 GW by 2020	3,527 MW
Netherlands	14% by 2021	---	---
Norway	28 TWh/yr by 2020	---	---
Portugal	31% of final energy consumption by 2020	5.3 GW land-based, 0.027 GW offshore by 2020	5,313 MW
Spain	---	6.4 GW added by 2020	---
Sweden	---	---	16.7 TWh
Switzerland	Increase generation by 22.6 TWh by 2050	4.3 TWh/yr by 2050 (with 0.7 TWh by 2020, 1.8 TWh by 2035)	---
United Kingdom	30% of electricity from renewable sources by 2020	No specific target but forecast of 20 GW by 2020	---
United States	Increase generation of electric power from renewables through cost reductions	Reduce land-based wind power to 0.052 USD/kWh (0.049 EUR/kWh), without incentives, by 2020, and to 0.031 USD/kWh (0.029 EUR/kWh) by 2030, and reduce the cost of offshore wind power to 0.149 USD/kWh (0.142 EUR/kWh) by 2020 and to 0.093 USD/kWh (0.088 EUR/kWh) by 2030	---

--- = No official target available

Table 10. Estimated Average Turbine Cost and Total Project Cost for 2016 in Reporting IEA Wind Countries

	Land-based Turbine Cost (EUR/kW; USD/kW)	Total Installed Land-based Project Cost (EUR/kW; USD/kW)
Austria	---	1,758; 1,851
Canada	---	***1,891; 1,991***
China	---	1,108; 1,167
France	---	1,330; 1,400
Germany	---	1,450; 1,527
Ireland	1,000; 1,053	1,750; 1,843
Italy	---	1,450; 1,527
México	1,476; 1,554	2,028; 2,135
Norway	855; 900	1,140; 1,200
Portugal	***1,308; 1,377***	***1,350; 1,422***
Spain	1,000; 1,053	1,200; 1,242
United States	950; 1,000	1,508; 1,588

Bold italic indicates estimate.
--- = No data available
Total Installed Project Cost includes: costs for turbines, roads, electrical equipment, installation, development, and grid connection.

Table 11. Potential Capacity Increases Beyond 2016 in Reporting Member Countries

Country	Planning Approval[a] (MW)	Under Construction[b] (MW)	Total (MW)
Austria	700	370	1,070
Canada	750	---	750
Denmark	(offshore) 978	(offshore) 407	1,385
Finland	400	529	929
France	2,239	---	---
Germany	---	(offshore) 1,198	1,198
Ireland	538	---	538
Korea	---	400	800
México	47	25	72
Norway	5,328	1,236	6,564
Portugal	---	(offshore) 25	25
Spain	500	0	500
Sweden	(land-based) 8,778 (offshore) 2,267	517	11,562
Switzerland	0	0	0
United Kingdom	(land-based) 844 (offshore) 1,818	(land-based) 2,810 (offshore) 1,976	7,488
United States	7,913	10,432	18,345

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

Activities of the IEA Wind TCP Research Tasks

The Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems—also known as the IEA Wind Technology Collaboration Programme (IEA Wind TCP)—operates under the auspices of the International Energy Agency (IEA). It is a collaborative venture among 26 contracting parties from 21 Member Countries, the Chinese Wind Energy Association (CWEA), the European Commission, and WindEurope.

Since its founding in 1977, participants have developed and deployed wind energy technology through vigorous national programs and co-operative international efforts. Participants also exchange the latest information on their current and future activities at semi-annual meetings and participate in selected IEA Wind TCP research tasks.

In 2016, the IEA Wind TCP had 15 active tasks working on wind energy research, development, and deployment (R,D&D). Through these co-operative tasks, the IEA Wind TCP Member Countries leverage their national efforts to complete larger and more complex projects than an individual organization could complete. Combined, these tasks bring together hundreds of experts from industry, government, and research institutions around the world to exchange information and participate in various research activities each year.

IEA Wind TCP research tasks focus on sharing the latest technologies and best practices to advance wind power deployment and help meet renewable energy goals. Figure 1 shows the various timelines for ongoing research tasks, and how each task fits into the IEA Wind TCP's priority areas. One new research task, Task 39 Quiet Wind Turbine Technologies, was approved in 2016 and will formally begin work in 2017. Task 33 on reliability concluded at the end of 2016.

The IEA Wind TCP conducted research activities that aligned with the consortium's Strategic Plan throughout 2016 [1]. The Strategic Plan aims to reduce wind energy costs by conducting R&D in five strategic areas:

- Characterize the wind resource to support reliable and cost-optimized technology
- Develop wind turbine technology for future applications such as large, highly reliable machines for offshore applications in shallow or deep waters
- Develop technology that facilitates the integration of this variable energy source into energy systems
- Improve existing methods to forecast electricity production from wind energy systems and to control wind power plants for optimal production and distribution of electricity
- Address challenges related to implementation uncertainties such as physical planning to optimize land use and minimize negative effects to people and nature.

Table 1 outlines these priority areas, objectives, and the active tasks directed at each priority area.

Task Participation

In 2016, each task had between five and seventeen participating countries working to solve issues related to wind energy technology and deployment (Table 2). 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) representative. In most projects, each participating organization agrees to carry out a discrete portion of the work plan. Often, a participation fee from member countries supports the OA's work of coordinating the research and reporting to the ExCo.

The IEA Wind TCP Executive Committee approves and oversees each research task. New tasks are added to the IEA Wind TCP as

Table 1. IEA Wind TCP Priority Areas and 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 TCP 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, 39
3: Wind Integration	●	●		●	11, 25, 37
4: Social, Educational, and Environmental Issues	●		●	●	11, 26, 27, 28, 34, 39
5: Communications			●	●	All

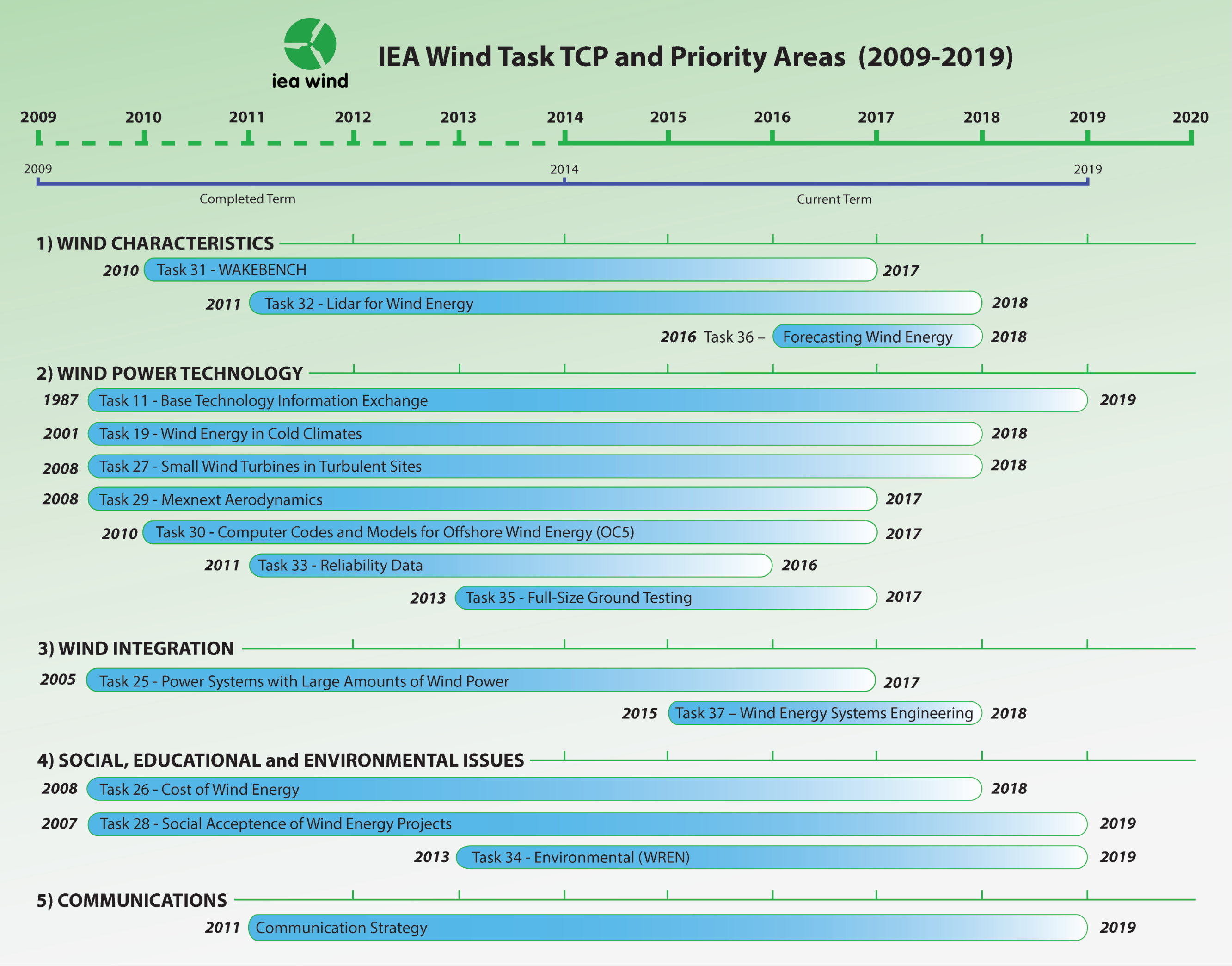

Figure 1. Priority areas from IEA Wind TCP Strategic Plan and active research tasks. [1]

Member Countries agree on new research topics for co-operation. Participating countries and sponsor members join tasks that are most relevant to their current national research and development programs. Organizations located within a member country and sponsor members are welcome to participate in research tasks. See Appendix A for additional information on 2016 membership.

Research Task Activities

The IEA Wind TCP made significant progress on several collaborative research efforts in 2016. Tasks regularly publish results and reports throughout their three-year activity period. Initial data and results are shared among participants, and final technical results are published after the conclusion of each three-year phase.

The IEA Wind TCP approved and published the following publicly-available reports in 2016:

- Task 19—*Available Technologies Report of Wind Energy in Cold Climates*
- Task 25—*Final Summary Report Phase 3: 2012–2014* (Grid Integration)
- Task 26—*Forecasting Wind Energy Costs & Cost Drivers*
- Task 26—*Expert Elicitation Survey on Future Wind Energy Costs*
- Task 26—Offshore Wind Farm Baseline Documentation
- Task 30—*Results of IEA Wind OC5 Project Phase 1.b: Deep Wind*
- Task 32—*State-of-the-Art Report: Recommended Practices for Floating Lidar Systems*
- Task 32—*Phase 1 Final Report: Wind Lidar Systems for Wind Energy Deployment*

Three Recommended Practices were drafted in 2016, which will be reviewed and published in 2017:

- *Recommended Practice 13 Edition 2: Wind Energy Projects in Cold Climates* (Task 19)
- *Recommended Practice 17: Wind Farm Data Collection and Reliability Assessment for O&M Optimization* (Task 33)
- *Recommended Practice 18: Floating Lidar Systems* (Task 32 in coordination with the Offshore Wind Accelerator initiative)

Task participants presented research findings at conferences, held workshops and webinars, and published numerous conference papers and journal articles throughout the year. Final reports, technical reports, research plans, and Recommended Practices produced by the tasks are available at www.ieawind.org.

Activities of the IEA Wind TCP Research Tasks

Table 2. Member Participation in Research Tasks During 2016

Participant*	Research Task Number														
	11	19	25	26	27	28	29	30	31	32	33	34	35	36	37
Austria		x			x					x				x	
Belgium		x								x					
Canada		x	x							x					
CWEA	x	x	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		OA	x	x
Greece										x					
Ireland	x		x	x	x	OA				x	x	x		x	
Italy	x		x					x							
Japan	x		x		x	x	x	x	x	x					
Korea					x			x		x					
México	x		x												
Netherlands	x		x	x			OA	x	x	x	x	x			x
Norway	x	x	x	x			x	x		x	x	x		x	x
Portugal			x					x				x		x	
Spain	x		x		OA		x	x	OA	x		x		x	x
Sweden	x	x	x	x			x		x		x	x		x	
Switzerland	OA					x			x	x		x			
United Kingdom	x	x	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	**15**	**11**	**18**	**9**	**8**	**6**	**10**	**13**	**11**	**17**	**11**	**10**	**5**	**13**	**7**

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

The following is a brief summary of the activities and accomplishments of each active task in 2016. Chapters 3–18 of this *IEA Wind TCP 2016 Annual Report* outline the research objectives and results of each active task. For more information about the ongoing co-operative research activities, contact the OA representative for each task listed at the end of each task chapter and in Appendix B of this report.

Task 11 Base Technology Information Exchange held three Topical Expert Meetings (TEMs) in 2016: Aerodynamics of Wind Turbines, Reducing Risk in the Financing of Offshore Wind, and Downwind Turbines. Proceedings from TEM 84 Aerodynamics of Wind Turbines were published on the IEA Wind TCP website, and proceedings from the subsequent meetings will be published online in 2017.

Task 11 also collaborates with other tasks to develop IEA Wind TCP Recommended Practices, which serve as pre-normative guidelines in advance of formal standards. In 2016, Task 11 assisted with the review of the three new Recommended Practices described above. These Recommended Practices will be published in 2017.

Task 19 Wind Energy in Cold Climates updated and finalized two reports during 2016: the *Available Technologies* report and the IEA Wind TCP *Recommended Practices 13 Ed 2: Wind Energy Projects in Cold Climates*. Additionally, participants updated their cold climate market study for 2015-2020, which was published in *WindPower Monthly* magazine in August 2016. The Task participants also attended two working group meetings, where they began work on the IEC 61400-15 standard, and were active members at eight international conferences. The free, open-source software, T19IceLossMethod, a standardized method for evaluating production losses due to icing with supervisory control and data acquisition (SCADA) data, is available on the Task 19 website.

Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power published a summary report that outlined the task's work during the 2012-2014 phase. Task 25 also collaborated on *Getting Wind and Sun onto the Grid: A Practical Manual for Policy Makers*, as well as a number of other articles. The task co-organized a session at the 2016 Wind Integration Workshop with IEA Paris and IEA Photovoltaic Power Systems (PVPS TCP) and presented their research at six other workshops.

Task 26 Cost of Wind Energy published *Forecasting Wind Energy Costs and Cost Drivers: Views of the World's Leading Experts,* the results of an expert elicitation survey of 163 of the world's foremost wind experts. This research was also published in *Nature Energy*. Task participants collected and published 2008-2012 wind plant technology cost and performance trends for several countries and will update the data annually. The task also initiated a new work package, wherein participants will use modeling analysis to understand how wind plant technology options affect the cost of wind energy.

Task 27 Small Wind Turbines at Turbulent Sites participants from Danish Technical University made significant progress researching the wind flow around and behind a 2-D "fence" in 2016. Their research will help identify the optimum building-roof shape for urban wind energy exploitation. Task 27 continues to research and refine areas addressed by the IEC 61400-2 standard on the safety, integrity, and design requirements of small wind turbines.

Task 28 Social Acceptance of Wind Energy Projects concluded its second phase in spring 2016, and the IEA Wind TCP Executive Committee approved a task extension in December of that year. Participants identified several priorities for Phase III work, which include increasing knowledge sharing, researching methods that will help industry work effectively with the public, and developing training practices for community engagement.

Task 29 Mexnext III Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models is working to develop a more complete understanding of wind turbine aerodynamics to improve aerodynamic models used for wind turbine design. In 2016, participants analyzed measurements from Danish Technical University and the New Mexico experiment measurement database. The task published the results of their analyses in papers and articles, and they presented five papers at the Science of Making Torque from Wind Conference in October 2016.

Task 30 Offshore Code Comparison Collaboration Continued, with Correlation (OC5) published the results from the Phase 1b in 2016. Participants also nearly completed their Phase II research, in which numerical models of the DeepCwind floating semisubmersible wind system were validated using measurement data from a 1/50th-scale test campaign. Task 30 is preparing to conduct Phase III on the Alpha Ventus offshore wind farm in 2017.

Task 31 Wakebench: Verification, Validation, and Uncertainty Quantification of Wind Farm Flow Models continued the Phase II work they began in 2015, including studies of the GABLS3 benchmark and the NEWA Ryningsnäs benchmark. Participants studied array effects in large wind farms and their dependency on inflow conditions with the OWA-Rødsand 2 experiment. The Task participants aim to adopt a framework for evaluating models and facilitate the development of a better integrated model chain covering all relevant scales for wind energy flow models.

Task 32 LIDAR: Wind Lidar Systems for Wind Energy Deployment organized four workshops in 2016 to understand and help mitigate the barriers to using lidar in wind energy deployment. In 2016, members from 13 countries participated in workshops. Workshops were held on: floating lidar systems, lidar-assisted control, lidar wake measurements, and uncertainty evaluation methods for different lidar configurations.

Task 33 Reliability Data: Standardization of Data Collection for Wind Turbine Reliability and Operation & Maintenance Analyses concluded operations in 2016. Participants finalized the IEA Wind TCP *Recommended Practice 17: Wind Farm Data Collection and Reliability Assessment for O&M Optimization,* which offers wind turbine operators and service providers individually appropriate solutions for wind farm data collection and reliability assessment for O&M optimization. This Recommended Practice is currently available for download at www.ieawind.org.

Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN) serves 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 wildlife challenges. In 2016, the Task expanded the WREN Hub website and published an *Adaptive Management White Paper*.

Task 35 Full-Size Ground Testing of Wind Turbines and their Components continued working in two subtasks that address blade and nacelle testing. The Nacelle Subtask workgroup defined a framework for test load cases using the design load cases in the IEC 61400 standard. The group presented their results at the 2016 World Congress and Exhibition for Renewable Energy and the WindEurope Summit Conference. The Blade Subtask developed a framework for defining and applying novel rotor blade subcomponent test methods.

Task 36 Forecasting for Wind Energy is working to improve the value of wind energy forecasts to the wind industry. Work Package 1 studies Numerical Weather Prediction (NWP) models, Work Package 2 examines power forecasting models, and Work Package 3 researches probabilistic forecast information. In 2016, a list of meteorological masts standing 100 m or greater was developed, which can be used for verification of wind profiles and wind speeds. Participants of Work Package 3 conducted a survey and structured interviews on the use of probabilistic forecasting.

Task 37 Wind Energy Systems Engineering: Integrated Research, Design, and Development began working on three Work Packages in 2016. Under Work Package 1, participants catalogued and identified analysis and design tools along with their associated disciplines and fidelities; their efforts resulted in a catalogue of existing multidisciplinary design analysis and optimization (MDAO) toolsets and a series of discipline/fidelity matrices. Work Package 2 began developing two reference turbines and Work Package 3 plans to benchmark MDAO activities at different system levels with activities set to begin in 2017.

Task 39 Quiet Wind Turbine Technology was officially approved for a three-year phase in December 2016, and its kick-off meeting will be held in 2017. The group intends to focus on three Work Packages, which will work on interdisciplinary education and guidance, aspects of technical noise, and the development of a Recommended Practice.

References

[1] *IEA Wind TCP End-of-Term Report 2009–2013 and Strategic Plan 2014–2019.* 2013; www.ieawind.org.

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 Topical Expert Meetings (TEMs), where invited experts exchange information on R&D topics of common interest to the IEA Wind members.

Task 11 also disseminates knowledge by developing IEA Wind TCP Recommended Practices for wind turbine testing and evaluation. Many of these documents have served as basis for both international and national standards. These cooperative activities have been part of IEA Wind since 1978.

Task 11 is an important instrument of the IEA Wind TCP, which allows members to react quickly to new technical and scientific developments and information needs. Reports and documents bring the latest knowledge to wind energy experts in member countries and present information and recommendations for the work of the IEA Wind TCP. Task 11 is also an important catalyst for starting new research tasks.

Following Task 11 meetings, attendees make resulting documents available to organizations in participating countries. Table 1 lists the countries participating in Task 11 in 2016. After one year documents can be accessed publicly at www.ieawind.org.

2.0 Progress and Achievements

Topical Expert Meetings

Topical Expert Meetings (TEMs) are conducted as workshops where information is presented and discussed in an open manner. Meetings are generally held over two days and oral presentations are expected from all participants. Three TEMs were held in 2016 and the meeting proceedings were published on the FTP server for participating members. They will be made available to the public one year after each meeting at www.ieawind.org.

TEM #84 Aerodynamics of Wind Turbines was jointly organized in coordination with the Task 29 MexNext meeting at NREL in Boulder, in the United States, 11-13 January 2016. The meeting gathered 16 participants representing seven countries: Denmark, Germany, the Netherlands, Norway, Spain, Sweden, and the United States. The goal was to gather knowledge on recent aerodynamic numerical and experimental techniques and developments to achieve a common understanding of the aerodynamic issues that affect wind turbines.

TEM #85 Reducing Risk in the Financing of Offshore Wind was hosted by RVO in Utrecht in the Netherlands, 18 May 2016 in coordination with Task 26: Cost of Wind Energy. Forty participants from nine countries participated: Belgium, Denmark, France, Germany, the Netherlands, Spain, United Kingdom, and the United States, as well as an observer from Luxembourg. This TEM focused on identifying actions available to various sectors in the offshore wind industry to identify, assess, and appropriately value risks in order to lower to overall offshore wind project cost.

TEM #86 Downwind Turbines was hosted by Hitachi in Tokyo, Japan, 3-4 November 2016. The meeting consisted of 12 technical presentations and was attended by 19 participants from Asia, Europe, and the United States, plus four observers from NEDO Japan. The purpose of the meeting was to organize a network to coordinate research and validation efforts for downwind turbines. The group would identify known benefits and potential barriers, areas needing additional research and validation, and opportunities for the reduction of cost of energy.

Recommended Practices

A second activity of Task 11 is to develop IEA Wind TCP Recommended Practices (RP). RPs originate from IEA Wind Task's collaborative research programs and are often drafted by participants as a final deliverable of the Task's work plan. In collaboration with the IEA Wind TCP Secretariat, Task 11 coordinates the review and approval process by the Executive Committee. IEA Wind TCP has issued 16 IEA Wind Recommended Practices; many of these documents have served as the basis for both national and international standards.

Three Recommended Practices were drafted in 2016 and will be reviewed and published in 2017:

- *Recommended Practice 13 Edition 2: Wind Energy Projects in Cold Climates* (Task 19)
- *Recommended Practice 17: Wind Farm Data Collection and Reliability Assessment for O&M Optimization* (Task 33)
- *Recommended Practice 18: Floating Lidar Systems* (Task 32 in coordination with the Offshore Wind Accelerator initiative)

3.0 Outcomes and Significance

Task 11 has been the backbone of IEA Wind TCP's activities for many years. The goal is to hold TEMs on four different wind energy research topics each year. Meeting topics selected by the IEA Wind TCP Executive Committee have covered the most important topics in wind energy for decades. Active researchers and experts from the

Table 1. Countries and Organizations Participating in Task 11 During 2016

County/Sponsor	Organization(s)
CWEA	Chinese Wind Energy Association (CWEA)
Denmark	Danish Technical University (DTU)
Finland	Technical Research Centre of Finland (VTT)
Germany	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU)
Ireland	Sustainable Energy Agency Ireland (SEAI)
Italy	Ricerca sul Sistema Energetico (RSE S.p.A.)
Japan	National Institute of Advanced Industrial Science and Technology (AIST)
Mexico	Instituto de Investigaciones Electricas (IIE)
Netherlands	Rijksdienst Voor Ondernemend (RVO)
Norway	Norwegian Water Resources and Energy Directorate (NVE)
Spain	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT)
Sweden	Energimyndigheten (Swedish Energy Agency)
Switzerland	Swiss Federal Office of Energy (SFOE)
United Kingdom	Offshore Renewable Energy Catapult (ORE)
United States	U.S. Department of Energy (DOE)

participating countries are invited to attend these meetings. A TEM can also begin the process of organizing new research tasks for the IEA Wind TCP.

Following the promising results and the high interest for TEM #86 on Downwind Turbines, the participants have expressed interested in organizing a new research task proposal. The goals of the proposed downwind turbine research collaboration would be to stimulate innovation in downwind turbine technology, to modify IEC standardization, and to reduce the cost of energy.

Aerodynamics Collaboration:

TEM # 84 held in conjunction with Task 29 meeting

As a community of wind energy experts, the IEA Wind TCP values collaboration between different tasks. In this context, the TEM #84 on Aerodynamics of Wind Turbines was organized in collaboration with Task 29 MexNext, focusing on aerodynamics measurement methods. The idea was to organize a "brainstorming" meeting on different aspects of aerodynamics. This TEM was coordinated in conjunction with a Task 29 participant meeting that was already planned at the National Renewable Energy Laboratory (NREL), United States.

4.0 Next Steps

So far, three TEMs have been planned for 2017:

- TEM #87 Smart Structures for Large Wind Turbine Rotor Blades, organized by DTU Wind Energy in Denmark, 27-28 April 2017
- TEM #88 Aero-elastic Codes Validation, organized by ORE Catapult and NREL, September 2017 in the United Kingdom
- TEM#89 Grand Vision for Wind Energy: Next Technology and Infrastructure Challenges to realize Wind's Full Potential, organized by NREL in October 2017. This TEM will serve as basis for the development of the IEA Wind TCP's new strategic plan.

The new operating agent, Planair SA (based in Switzerland), has taken over the management of Task 11 for 2017. One of the important tasks in 2017 will be selecting and launching an online community platform for Task 11 participants. The aim is to provide a structure for the wind energy expert community and a common platform to see which experts are working on which topics. The platform should facilitate basic information exchange within the expert community and thus help identify new interesting topics for future TEMs (and potentially new tasks).

References:

Opening photo: Mounting the hub at Gütsch, Switzerland (Photo credit: ©Suisse Eole)

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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 (which leads to higher energy yields), low population densities (fewer social impacts), and increasing technological solutions. However, icing of turbines and low ambient temperatures pose additional challenges for wind energy projects that require special attention.

The objective of this expert group is to gather and provide information about wind energy in cold climates, including project development, operation and maintenance (O&M), health, safety and environment (HSE), operational experiences, and recent research. The vision of IEA Wind TCP Task 19 is to enable large-scale deployment of cold climate wind power in a safe and economically feasible manner.

The expected results and deliverables of Task 19 are:

- **Publish a cold climate wind power market study update for 2015-2020 in *WindPower Monthly* magazine.**
- **Include cold climate aspects into International Electrotechnical Commission (IEC) standard 61400-15, Edition 1 "Site Energy Yield Assessment"**
- **Validate and further develop T19IceLossMethod free software**
- **Develop and publish turbine ice protection system (anti- and de-icing systems) performance evaluation guidelines**
- **Develop and publish international ice throw guidelines**
- **Update the *Available Technologies Report* and *Recommended Practices 13, Edition 2: Wind Energy Projects in Cold Climates*.**

Currently, the Task is engaged with consultants, owner/operators, developers, turbine manufacturers and component manufacturers working in wind energy sector.

2.0 Progress and Achievements

In 2016, the main activities were in finalizing the *Available Technologies* and *Recommended Practices* reports from the 2013-2015 term. In addition to these reports, work started for the IEC 61400-15 standard by participating in two working group meetings in the United States and Denmark.

The most important publications in 2016 were:

- Cold climate market study update for 2015-2020, published in August 2016 [1]
- *Available Technologies*, published in May 2016 [2]

The cold climate market study showed a significant growth rate of 12 GW/yr being built in cold climate areas from 2016 to 2020, representing 30% of all new wind farms—making this the largest "non-standard" wind energy market today (Figure 1).

Task 19 was active at eight international conferences (Finland, Germany, Sweden, United Kingdom, and the United States) totaling 19 public conference session chairmanships, presentations, and workshops.

3.0 Outcomes and Significance

The cold climate wind industry and research communities are in a public outcry for standardized vocabulary and methods for working in cold climates. Task 19 has heard this need, and all efforts within Task 19 are focused towards standardization and recommended practices.

With a standardized vocabulary, it is possible to harmonize research results as well as communicate results to the industry in a unified manner, increasing the impact substantially. By having recommended practices and standards, the wind industry can start developing new solutions and innovations in a more focused

Available Technologies Report

The *Available Technologies* report's target audience is engineers, consultants, and other technical end-users that need reliable, up-to-date information about the most recent cold climate solutions fast and efficiently.

The report's core content consists of summary tables providing an easy and quick user interface to all known solutions, ranging from cold climate weather models to icing maps, available ice detectors, icing models, cold climate turbines, general ice throw guidelines, operation and maintenance solutions, useful standards, and available testing laboratories and sites. The report has over 400 references, making it a massive data source for anyone in need of cold climate technological solutions.

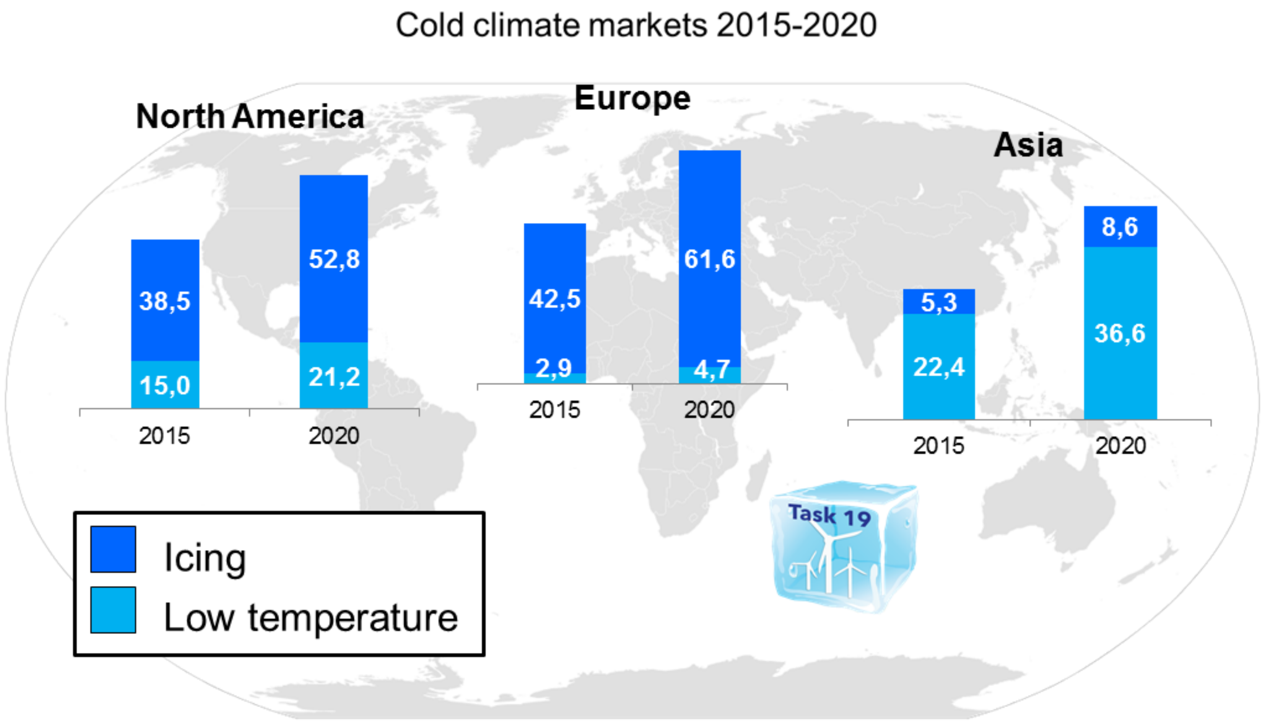

Figure 1. Existing and forecasted cold climate market size in gigawatts 2015-2020 (Source: *WindPower Monthly* magazine August 2016 edition)

manner opposite of the current "wild west" way of working. With the efforts of Task 19, development of wind farms in cold climates will be substantially more affordable and safe.

4.0 Next Steps

In 2017, Task 19 plans to:

- Finalize *Recommended Practices 13 Edition 2*
- Start working with ice protection system performance evaluation guidelines by organizing two industry workshops
- Start working with international ice throw guidelines by organizing two industry workshops
- Continue working with IEC 61400-15 standard

References:

Opening photo: A wind farm consisting of Bonus 600 kW wind turbines with electrothermal anti-icing systems installed on Olos fjell, Finland (Photo credit: A.Vignaroli, VTT)

[1] IEA Wind Task 19 (2016). *Emerging from the cold.* Download from: www.windpowermonthly.com/article/1403504/emerging-cold

[2] IEA Wind Task 19 (2016). *Available Technologies Report.* Download from: www.ieawind.org/task_19/State%20of%20the%20Art%20Task%2019/052516/Task%2019_Available_Technologies_report_WEinCC_May2016_approved.pdf

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

Table 1. Countries and Organizations Participating in Task 19 During 2016

Country/Sponsor	Organization(s)
Austria	Energiewerkstatt Verein
Belgium	OWI-LAB
Canada	Technocentre éolien
CWEA	Chinese Wind Energy Association (CWEA)
Denmark	Technical University of Denmark (DTU) Wind Energy
Finland	VTT Technical Research Centre of Finland
Germany	Fraunhofer Institute for Wind Energy and Energy System Technology (IWES)
Norway	Kjeller VindTeknikk
Sweden	WindREN
Switzerland	Meteotest
United Kingdom	DNV GL

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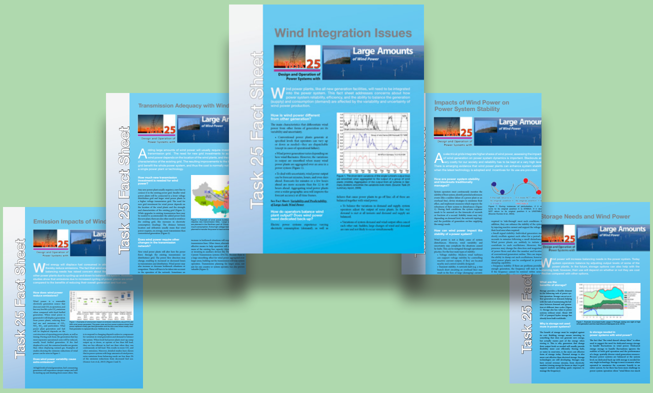
Task 25

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

1.0 Introduction



The variable and unpredictable nature of wind power introduces uncertainty into operating a power system. To meet this challenge, power systems need more flexibility—though how much is needed depends on the amount of wind power and the power system's existing flexibility. Existing wind power targets anticipate a high share of wind-generated electricity in many countries. Wind integration studies are important measures to make sure power systems can accommodate expected amounts of wind power. Several countries are releasing real-life wind integration experiences in addition to studies.

It is difficult to compare integration study results because they use different methodologies, data, and tools, as well as different terminology and metrics, to represent the results. Therefore, it is important that each country apply commonly accepted standard methodologies. The IEA Wind TCP Task 25 summarizes results from participating countries and formulates best practice recommendations for system impact and integration studies. Task 25 started in 2006 and is now in its fourth term, 2015–2017.

2.0 Progress and Achievements

The IEA Wind TCP Task 25 provides information that facilitates economically feasible wind energy penetration in electricity power systems worldwide. Participants analyze and develop methodologies that assess the impact of wind power on power systems. Task 25 has established an international forum for member countries and Transmission System Operators (TSOs) to exchange knowledge and experiences related to power system operations with large amounts of wind power.

The Danish system operator Energinet.dk. hosted the 2016 spring Task meeting in Fredericia, Denmark. Strathclyde University hosted the autumn meeting in Glasgow, Scotland. Both 2016 meetings were joint, back-to-back meetings with other Tasks: the spring meeting with IEA PVPS Task 14 on solar integration, and the autumn meeting with the IEA Wind TCP Task 26 Cost of Wind Energy, discussing the value of wind energy from power system and electricity market simulations.

System operators for Denmark, France, Italy, the Netherlands, and Quebec, Canada were active in Task 25 work in 2016. Task 25 follows the activities of the Institute of Electrical and Electronics Engineers (IEEE) in new working groups for flexibility and operation of power systems.

Task 25 also contributes to the IEA GIVAR project. In 2016, the Task collaborated on *Getting Wind and Sun onto the Grid: A Practical Manual for Policy Makers.* The Task's collaboration with IRENA also progressed in 2016. IRENA observers presented in Task 25 meetings and Task 25 commented on IRENA's integration topic reports.

The Task's work has been used to make best practice recommendations (*IEA Wind Recommended Practices: 16 Wind Integration Studies*, published in 2013) and integration fact sheets (opening figure). The latest summary report was published in 2016.

3.0 Outcomes and Significance

Publication is a key goal of Task 25 cooperative research. In addition to the Task 25 summary report, the Task published the following collaborative articles in 2016:

- "Wind and Solar Energy Curtailment: A Review of International Experience" (L. Bird et al), *Renewable & Sustainable Energy Reviews*
- "Wind Integration Impacts in Hydro-dominated Systems" (D. Huertas Hernando et al), Wiley's *WIRES* (DOI:10.1002/wene.220)
- "Capacity Value of Wind" (M. Milligan et al), Wiley's *WIRES* (DOI:10.1002/wene.226)
- "Power System Stability Issues" (D. Flynn et al), Wiley's *WIRES* (DOI:10.1002/wene.216)

Task 25 co-organized a session at the 2016 Wind Integration Workshop (WIW2016) in Vienna with IEA Paris and IEA Photovoltaic

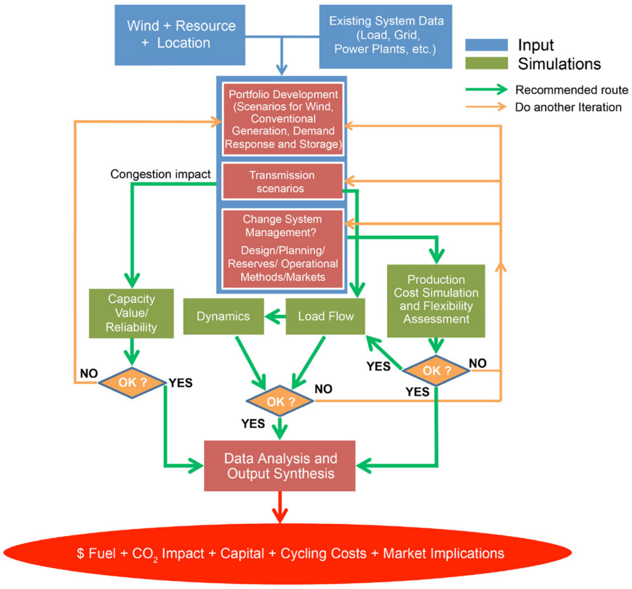


Figure 1. Flow chart of a complete wind integration study, showing relevant iteration loops from simulations to set-up and portfolio development

Power Systems Programme (PVPS) Task 14. Task 25 also presented in:

- INESC TEC workshop and LNEG workshop in Portugal, February 2016 (H. Holttinen)
- Austrian Wind Energy Symposium 2016, Vienna, March 2016 (H. Holttinen)
- IEA/ISGAN workshop "Flexibility in Future Energy Systems" in Paris, October 2016 (H. Holttinen)
- Sustainable Energy Authority Ireland (SEAI) seminar on International Wind Energy R&D Collaboration, Dublin, Ireland, October 2016 (J. Dillon)
- WindFinland workshop, Tampere, Finland, October 2016 (H. Holttinen)

Task 25 brings best practice wind integration experience, study methods, and results to member countries and a wider audience through IEA, IRENA, UVIG, IEEE, and various Task publications.

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

Country/Sponsor	Organization(s)
Canada	Hydro Quebec/Hydro Quebec Research Institute (IREQ)
CWEA	State Grid Energy Research Institute (SGERI)
Denmark	Technical University of Denmark (DTU); Transmission System Operator Energinet.dk
Finland	VTT Technical Research Centre of Finland
France	EdF R&D (Electricite de France); Transmission System Operator RTE; Mines Paris Tech
Germany	Fraunhofer Institute for Wind Energy and Energy System Technology (IWES); Transmission System Operator Amprion
Ireland	University College Dublin (UCD); Sustainable Energy Authority of Ireland (SEAI)
Italy	Transmission System Operator Terna
Japan	Tokyo University; Kansai University; Central Research Institute of Electric Power Industry (CRIEPI)
México	Instituto Nacional de Electricidad y Energías Limpias (INEE)
Netherlands	Transmission System Operator TenneT; Delft University of Technology (TUDelft)
Norway	SINTEF Energy Research
Portugal	Laboratório Nacional de Energia e Geologia (LNEG); Institute for Systems and Computer Engineering, Technology and Science (INESC TEC)
Spain	University of Castilla-La Mancha
Sweden	Royal Institute of Technology (KTH)
United Kingdom	Imperial College; Strathclyde University
United States	National Renewable Energy Laboratory (NREL); Utility Variable Generation Integration Group (UVIG); U.S. Department of Energy (DOE)
WindEurope	WindEurope (formerly EWEA)

Note: 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.

Wind and Solar Integration Tasks Collaborate on Integration Studies

Ongoing experience and studies that provide data on system-wide wind power production, improved modeling, and integration of wind and solar in future power systems are helping to evolve integration study methods. Task 25 published *Recommended Practice 16: Wind Integration Studies* on how to perform an integration study in October 2013. Current work seeks to update this report to cover solar PV though collaboration with IEA PVPS Task 14.

A complete integration study is usually an iterative process (Figure 1). Wind integration studies usually involve simulations of the power plants in the system and investigations of grid and generation capacity adequacy (the green boxes in the flow chart, Figure 1). A more detailed level includes dynamic simulations and a flexibility assessment, which are necessary when studying higher penetration levels of wind power.

Analyzing and interpreting results of integration studies is not straightforward. The assumptions and setups of the study (such as investments in the remaining system) are crucial to determining the integration impacts and costs. Because system costs are difficult to allocate to any single plant or technology, integration studies aim to quantify increases in power system costs. Another approach to allocating system costs is cost-benefit analysis. Adding wind power to power systems will reduce total operating costs and emissions as wind replaces fossil fuels.

4.0 Next Steps

Sustainable Energy Authority of Ireland (SEAI) hosted Task 25's 2017 spring meeting in Dublin, Ireland. The fall meeting is planned for Mexico, hosted by CEMIE Eólico. The Recommended Practices for integration studies, including solar PV, should be published in 2017, the final reporting year of phase four. The Task will be working on updating fact sheets, wind power time series database, bibliography and summary report.

In 2017, Task 25 will draft journal articles and conference presentations about critical modeling issues in wind integration studies. These will include comparisons of studies with high shares of wind energy, integration costs, planning and operational time scale modeling, electricity market design, curtailments and forecast error modeling.

Task 25 participants will present their work at several meetings in 2017, including the IEEE PES conference in July, the Wind Integration Workshop 2017 (WIW17) in Berlin, and at national conferences in Ireland and Sweden.

References:

Opening figure: Task 25 Wind Integration Fact Sheets (2015).

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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 intends to reduce the cost of energy, but market drivers—including fluctuations in commodity and fuel prices—also impact the cost. Wind energy costs differ among countries, and comparison is difficult.

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

Phase three of Task 26 began in October 2015 and will continue through September 2018. During this phase, Task participants expect to:

- **Enhance international collaboration and coordination in the field of cost of wind energy**
- **Update data, analysis, and understanding of land-based wind energy cost trends in each country**
- **Identify primary offshore wind energy cost drivers and how these costs vary among participating countries**
- **Collaborate on journal articles that analyze and summarize current efforts to understand trends in cost of energy**
- **Collaborate on journal articles that explore issues related to the value of wind energy.**

Nine IEA Wind TCP Members, representing 12 distinct organizations with participation from over 20 individuals, continued their contributions to Task 26 in 2016 (Table 1).

2.0 Progress and Achievements

In 2016, Task 26 focused on:

- Updating land-based wind project-level statistics required for cost of energy calculations
- Assessing offshore wind data and information needed to estimate the cost of offshore wind energy
- Initiating a European electric sector forecast analysis, which explores how wind turbine technology trends affect future electricity system costs
- Publishing a survey of wind energy experts to elicit perspective on future cost reduction potential for land-based, fixed-bottom offshore, and floating offshore wind technologies.

Task 26 collected and published the 2008-2012 wind plant technology cost and performance trends for Denmark, European Union, Germany, Ireland, Norway, and the United States [1,2]. Future publications will include wind projects in Sweden.

Statistical trends in wind plant and turbine technology, cost, and performance will be updated annually on the Task 26 website. Going forward, this will allow for more current representation of the basic cost of energy parameters. A report exploring trends in technology, wind plant resource conditions, project cost elements and refined cost of energy estimates is planned for 2018.

Because offshore wind energy costs are site-specific and currently concentrated in a small number of markets, Task 26 devised an approach for consolidating data among participating countries. Data and model estimates for existing and planned offshore wind projects were combined and compared. This data was used to develop a baseline representation of the physical characteristics of a typical offshore wind plant [3]. This approach analyzes cost drivers based on information provided by the various participants. It will represent offshore wind project costs generically, rather than specifically to those countries where projects are in operation. The Task is also considering methodologies to compare the impact of these drivers.

Task 26 also initiated a new work package, exploring the value of wind energy in the electric sector. As wind energy quantities increase, time-varying prices fluctuate. Participants plan to use modeling analysis to understand how wind plant technology options, such as larger rotors and taller towers, can affect this price variation. The technology trends and differences among countries that resulted in earlier publications provide the basis for this future-looking analysis.

3.0 Outcomes and Significance

Ultimately, the work of Task 26 intends to inform policy and regulatory communities of the current and future cost of wind energy for both land-based and offshore wind technologies. By providing high quality data that supports analyses related to cost of wind energy, the Task enhances the broader energy analysis community's efforts. Organizations such as IEA and the International Renewable Energy Agency (IRENA) have used Task 26's wind project cost and performance statistics, and Task 26 participants regularly use this data for internal and external purposes.

Collaboration among participants provides insights and knowledge that benefit all participating organizations. Regarding the cost of offshore wind, collective explorations of costs and cost drivers have led to improved knowledge among the representatives of countries with existing offshore wind plants and those exploring feasibility of offshore wind. Analysts may use a public report describing in detail the cost elements for a baseline offshore wind plant to assess offshore wind cost of energy.

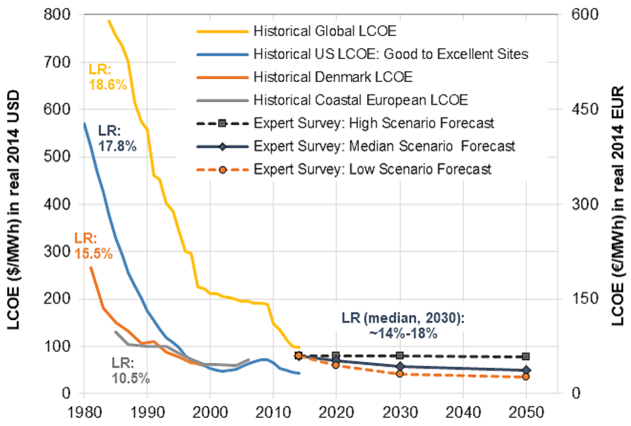

Figure 1. Historical and forecasted land-based wind LCOE and learning Rates [5]

Table 1. IEA Wind Members Participating in Task 26 During 2016	
Country/Sponsor	Organization(s)
Denmark	Denmark Technical University (DTU); Ea Energy Analyses
European Commission	Joint Research Centre
Germany	Deutsche WindGuard; Fraunhofer Institute for Wind Energy and Energy System Technology (IWES)
Ireland	Dublin Institute of Technology (DIT)
Netherlands	TKI Wind-op-zee
Norway	Norwegian Water Resources and Energy Directorate (NVE)
Sweden	Swedish Energy Agency (SEA)
United Kingdom	Offshore Renewable Energy Catapult (ORE)
United States	National Renewable Energy Laboratory (NREL); Lawrence Berkeley National Laboratory (LBNL)

Experts Weigh in on Future Wind Energy Cost Forecasts

IEA Wind TCP Task 26 investigates the current state and cost of wind energy technologies to determine 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 [5, 6]. This is the first large-scale global expert elicitation survey on future wind energy costs and related technology advancements. With over 160 experts participating, it is also the largest known energy technology expert elicitation ever performed.

Figure 1 illustrates the expert survey projections of future cost of land-based wind energy. Their projections were based on three scenario forecasts relative to historical cost of energy. The median scenario envisioned by the experts reflects a learning rate in 2030 that is similar to the historic learning rates. This study provides perspectives on future cost of energy that can be used by entities forecasting future electric sector evolution under a variety of technology, market and policy conditions.

4.0 Next Steps

In the coming year, Task 26 participants will continue to explore the cost of wind energy by:

- Updating land-based wind project statistics through 2016 accessible through a dynamic web application
- Publishing a report discussing the cost drivers of offshore wind energy, both technical and policy-related, and differences among participating countries
- Disseminating a report exploring the impact of technology trends to larger rotors and taller towers on future European electric sector development

References

Opening photo: IEA Wind TCP Task 26 Project Meeting 12 in May 2016 at Fraunhofer IWES, Bremerhaven, Germany (Photo Credit: Marcel Wiggert)

[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

[2] Lantz, E.; Wiser, R.; Hand, M. (2012). *IEA Wind Task 26 – The Past and Future Cost of Wind Energy; Work Package 2 Final Report*. NREL/TP-6A20-53510. Download from www.nrel.gov/docs/fy12osti/53510.pdf and ieawind.org/task_26.html

[3] Vitina, A., Lüers, et. al. (2015). *IEA Wind Task 26: Wind Technology, Cost and Performance Trends in Denmark, Germany, Ireland, Norway, the European Union, and the United States: 2007 - 2012*. 163pp.; NREL Report No. TP-6A20-64332. Download from www.nrel.gov/docs/fy15osti/64332.pdf and ieawind.org/task_26.html

[4] Lacal-Arántegui, R.; M. M. Hand; D. Radu; D. Magagna. (2014). *A System-based Approach to Assessing the Value of Wind to the Society.* Report based on an experts' workshop held in Petten, Netherlands, 13–14 November, 2013. European Commission-Joint Research Centre. Download from http://setis.ec.europa.eu/publications/jrc-setis-reports/system-based-approach-assesing-value-of-wind-society and ieawind.org/task_26.html

[5] Wiser, R., K. Jenni, J. Seel, E. Baker, M. Hand, E. Lantz, and A. Smith. (2016). *Forecasting Wind Energy Costs and Cost Drivers: The Views of the World's Leading Experts.* Berkeley, CA: Lawrence Berkeley National Laboratory. LBNL-1005717. June 2016. Download from https://emp.lbl.gov/publications/forecasting-wind-energy-costs-and and ieawind.org/task_26.html

[6] Wiser, R., K. Jenni, J. Seel, E. Baker, M. Hand, E. Lantz, A. Smith. 2016. "Expert Elicitation Survey on Future Wind Energy Costs." *Nature Energy*. No: 16135. Accessed January 2017. doi:10.1038/NENERGY.2016.135.

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Task 27

Small Wind Turbines in High Turbulence Sites

1.0 Introduction

The goal of IEA Wind TCP Task 27 is to understand how turbulence impacts small wind turbine production and whether turbulence is appropriately characterized in the International Electrotechnical Commission (IEC) standard 61400-2 for small wind turbines. Historically, Task 27 has held back-to-back meetings with IEC Maintenance Team 2, a group of experts re-writing IEC 61400-2. Participants discussed IEC standard requirements for turbulence parameters, turbulence models, and sensitive load cases, which may differ from the current requirements that were historically taken from the large wind IEC standard 61400-1.

Experts recognized the need for global, shared research on turbulence parameters for high turbulence cases. While there are a number of existing 3-D wind resource data sources, no ongoing research exists to help experts write better turbulence requirements. On some occasions, small commercial wind turbine projects have produced less electricity than expected when compared to production estimates based on independent testing results. This inconsistency has led to confusion among consumers regarding actual turbine production.

This lack of data and inconsistent production are linked to the turbulent environment where small wind turbines are installed. Highly turbulent sites where small wind turbine consumers live and work may have less efficient turbine production than estimated. Is it possible to conduct a global research effort to measure and model wind speed and direction for typical and worst case (rooftop) consumer sites? Is it possible to model wind interferences on a micro-scale to provide more accurate production estimates?

There are two primary goals for the work done under IEA Wind TCP Task 27. The first is to conduct global, shared research to better understand technical parameters within IEC 61400-2, and the second is to take these research findings and publish the results in a useful, practical guide on micro-siting small wind turbines.

2.0 Progress and Achievements

Task 27's work required analyses of existing 3-D wind resource data, collection of new 3-D data combined with analyses and CFD models to help analyze 3-D turbulent inflow and directional variability. Some of the new data measurements have been validated with CFD, and other data measurements have been used to inform small wind turbine performance predictions and models.

Task 27 conducted a total of four meetings in 2016–two virtual meetings (in January and June) and two face-to-face meetings. The January virtual meetings were attended by nine experts from Austria, Argentina (Observer), China and Taiwan, Denmark, Ireland, Spain, and the United States. The second virtual meeting was attended by a total of nine experts from five countries (Austria, China, Ireland, Spain and the United States).

The first Task 27 face-to-face meeting for 2016 was held in Taipei, Taiwan, and hosted by the Taiwan Small and Medium Wind Turbine Association (TSWA) and Taiwan Institute of Economic Research (TIER) in April. This meeting was attended by 34 experts from ten countries: Austria, China (Mainland and Taiwan), Denmark, Ireland, Japan, Korea, Spain, South Africa (Observer) and the United States. Twenty-two presentations were given by research organizations, manufacturers, and academic experts.

The second face-to-face meeting was held in Hurup Thy, Denmark, hosted by the Technical University of Denmark (DTU) Wind Energy, the Nordic Folkecenter for Renewable Energy, and the Danish Small Wind Energy Association in September 2016 (Figure 1).

Several meetings have been held to allow for outreach to the wider small wind turbine audience including:

- 7th World Summit for Small Wind New Energy in Husum, Germany, 17-18 March 2016
- 2nd Internationale Kleinwindtagung in Wien, Austria, 15 September 2016
- Foro Internacional Sobre Energía Eólica, Cutral Co, Argentina, 14-18 November 2016

3.0 Outcomes and Significance

IEC 61400-2 Maintenance Team 2 is scheduled to revise the standard in 2018. All of Task 27 participant's case studies, technical results, papers and presentations can be used as a basis for the next revision. Having an international standard that better reflects typical consumer sited small wind turbines will help ensure that the technical design requirements meet market demands.

4.0 Next Steps

In 2017, Task 27 plans to:

- Compile country case studies documenting of all the research, modeling and testing efforts conducted within Task 27
- Discuss and complete the list of technical considerations for the future IEC 61400-2 standard, fourth revision
- Draft an IEA Wind TCP Recommended Practices on micro-siting of small wind turbines, a practical, useful guide on the

importance of good micro-siting for small wind turbines, guidelines for good micro-siting, and models and tools to more accurately predict wind turbine performance based on detailed site input.

Understanding Wind Flow Around and Behind a 2-D 'Fence'

In 2016, Davide Conti, Peggy Friis and others from the Danish Technical University made significant progress toward understanding the wind flow around and behind a 2-D 'fence' [1, 2]. Researchers measured wind flow around a solid fence that blocked 100% of the inflow and a porous fence that blocked less than 100%. These measurements informed input into WAsP and led to the creation of myturbine.com, a small wind turbine performance predictor that accounts for blockages and wind direction.

The optimum building-roof shape for the urban wind energy exploitation has been identified and analyzed by Francisco Toja from CIEMAT, Spain [3]. This investigation focused on two aspects: the isolated building shape optimization and the analysis of this building in an urban environment. Experts compared velocity, turbulent kinetic energy, and turbulence intensity to site a wind turbine on the roof. They concluded that slender shapes are the most interesting building shapes for wind energy exploitation, leading to a higher speed-up and to lower turbulence intensity.

Also related to this research, Takaaki Kono from Kanazawa University in Japan, investigated the effects of wind direction and horizontal aspect ratio (HAR = width/length) of a high-rise cuboid building on wind conditions above the roof [4].

These activities will be concluded at the end of 2018 and be shared with IEC 61400-2 fourth revision experts.

References:

Opening photo: Solid Wind SWP 25 wind turbine (Photo credit: Davide Conti, DTU)

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Figure 1. Task 27 attendees at the Nordic Folkecenter, Denmark, 2016 (Photo credit: Ignacio Cruz)

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Task 27 Small Wind Turbines in High Turbulence Sites
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Table 1. Countries and Organizations Participating in Task 27 During 2016

Country/Sponsor	Organization(s)
Austria	University of Applied Sciences Technikum Wien (UASTW)
CWEA	Chinese Wind Energy Association (CWEA); Inner Mongolia University of Technology (IMUT); Taiwan Small and Medium Wind Turbine Association (TSWA)
Denmark	Technical University of Denmark (DTU)
Ireland	Dundalk Institute of Technology (DKIT)
Japan	Institute of Science and Engineering; Kanazawa University (KU)
Korea	Korea Institute of Energy Technology Evaluation and Planning (KETEP)
Spain	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT)
United States	National Renewable Energy Laboratory (NREL)
Mexico (New partner in 2017)	Centro Mexicano de Innovación en Energía Eólica (CEMIE Eólico)
Argentina (observer)	Instituto Nacional de Tecnología Industrial (INTI)
South Africa (observer)	Nelson Mandela Metropolitan University (NMMU)

Task 28

Social Acceptance of Wind Energy Projects

1.0 Introduction

Wind energy forms an important part of policy goals in IEA Wind TCP member countries working to meet their renewable energy obligations. However, social acceptance continues to be a key constraint on the development of wind energy projects. Projects that encounter concerned host communities—and, in some cases, opposition—can have increased costs and timelines, which decrease the overall rate of wind energy deployment.

In the face of the intensifying and dynamic challenge of social acceptance of wind energy in most parts of the world, IEA Wind TCP Task 28 on Social Acceptance of Wind Energy Projects serves as an international forum and working group involving Denmark, Germany, Ireland, Japan, Switzerland, and the United States.

To achieve renewable energy policy objectives, social acceptance needs to focus on the needs of all stakeholders such as policy makers, regulators, developers, local communities and special interest groups. For the purposes of the Task 'social acceptance' was defined as a favorable or positive response relating to proposed or developed technology by members of a given social unit (country or region, community or town and household, organization) [1].

2.0 Progress and Achievements

Phase II of Task 28 concluded in spring 2016, and the IEA Wind TCP Executive Committee granted a task extension Phase III 2017-2019 at the December 2016 ExCo meeting.

According to a survey of potential participants, priorities for this next phase include:

- Transform research into practice
- Pursue collaborative research efforts
- Enhance participation of practitioners from the wind energy industry
- Create new and novel research that can help better discern appropriate policies and mechanisms for working with the public
- Develop a common approach to training industry community engagement practitioners
- Improve the quality of communication between developers and host communities
- Increase task participation by national planning authorities and regulators
- Explore new mechanisms for knowledge exchange between researchers, practitioners and policy makers
- Share good practice, research ideas and methods to enhance participating country insights as well as cross-cultural understanding of the challenges

3.0 Outcomes and Significance

Debates surrounding wind energy projects in the field show that social acceptance is a topic that needs to be better understood if various policy targets for renewable energy production are to be accomplished. Individual projects require public approval, and to be realized proponents and opponents need to work together to improve projects. Industry, government, and research institutions appear to be increasingly interested in these topics (e.g., quantification or monitoring).

Achieving long-term acceptance of wind power will require efforts such the interdisciplinary and international Task 28 approach.

Priority Topics for Task 28 Phase III (2017-2019)

Potential Task participants helped identify four Work Packages for Phase III of Task 28 though a survey conducted in 2016:

1. Knowledge creation, exchange and co-production of innovation in social acceptance
2. Offshore wind energy: unique challenges of social acceptance
3. Using regulatory processes and consenting regimes to promote social acceptance
4. Enhancing the effectiveness of research in social acceptance of wind energy

Figure 1 shows the intersection of these Work Packages across the three themes of the Task.

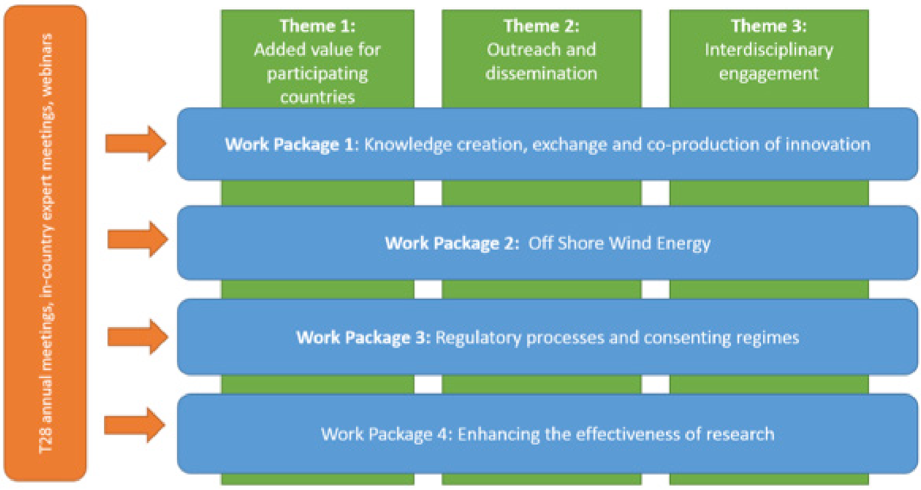

Figure 1. Priorities, themes, and work packages developed for phase three of Task 28

4.0 Next Steps

The first meeting of Phase III was scheduled for 30-31 March 2017 in Dublin, Ireland to further define the work plan and coordinate national research activities.

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Table 1. Countries and Organizations Participating in Task 28 Phase III

	County/Sponsor	Organization(s)
1	Denmark	Danish Energy Agency; Technical University of Denmark (DTU)
2	Germany	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety; Martin Luther University; University of the Saarland
3	Ireland	Sustainable Energy Agency Ireland (SEAI); Queen's University Belfast
4	Japan	National Institute of Advanced Industrial Science and Technology; Nagoya University
5	Switzerland	Federal Department of the Environment, Transport, Energy and Communications; Swiss Federal Office of Energy (SFOE); ENCO Energie-Consulting AG
6	United States	U.S. Department of Energy (DOE); National Renewable Energy Laboratory (NREL) National Wind Technology Center; Lawrence Berkeley National Laboratory (LBNL)

Task 29

Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models

1.0 Introduction

Modeling wind turbine response (i.e., the power, load, and stability) is subject to large uncertainties, and the main 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. As a good illustration of the extreme complexity of fluid dynamics, aerodynamics is the subject of one of the seven millennium prize problems established by the Clay Mathematics Institute of Cambridge.

Wind turbines have extreme aerodynamic uncertainties because they are exposed to very complex aerodynamic phenomena at stalled or yawed conditions where their huge size adds complexity (e.g., non-uniform inflow and structural flexibility).

The objective of the IEA Wind TCP Task 29 Mexnext is to form a more complete understanding of wind turbine aerodynamics to improve aerodynamic models used for wind turbine design. The third phase of Mexnext, started in January 2015, is largely based on the New Mexico experiment. This experiment took place in July 2014, when researchers took measurements in the Large Low Speed Facility of the German Dutch Wind Tunnel DNW as a follow up of the Mexico experiment carried out in December 2006. Other public field and wind tunnel measurements form input as well.

2.0 Progress and Achievements

In 2015, the New Mexico measurement database and detailed descriptions were provided to Task participants. These measurements were used to define a calculational round at aligned conditions and three wind speeds. Generally, the agreement between calculated and measured flow field was very good. When comparing CFD results with the New Mexico measurments, the calculated loads were in better agreement with measured values from comparisons made in Mexnext-I [2].

Figure 1 shows the measured normal force as a function of radial position compared with calculations. The spread in BEM results is limited; however, it should be noted that all participants use the same airfoil data. The spread was larger in earlier rounds of calculations when participants applied their own corrections to airfoil data.

Researchers are currently studying the relatively large spread in CFD results. Participants expect the result to be partly related to grid topology, domain size, and code characteristics (e.g., compressible vs. incompressible). The poor agreement between calculations and measurements at 60% span may be attributable to the fact that airfoil data at the appropriate conditions in terms of Reynolds number and tripping are available for two out of the three airfoils on the Mexico blade, but are not for the RISOE airfoil, which is the airfoil at 60% span.

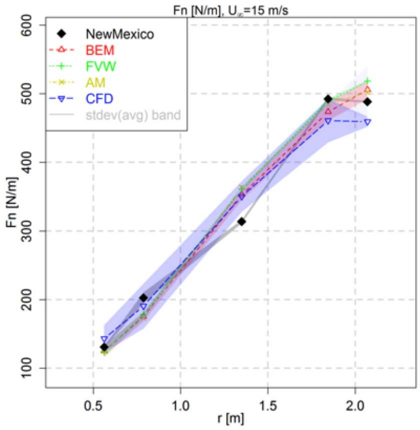

Figure 1. Normal force as function of radial position, measured and calculated at design conditions

The New Mexico measurements are improving the understanding of aerodynamic phenomena for IEC aerodynamics subjects. Measurements were analyzed with a pitch offset on one blade. This imbalance has been found to affect the pressure distribution of the unaffected blades as well. CFD models were able to predict the effects from the imbalance reasonably well, at least better than more simplified models. Results have been published and presented in numerous papers and articles (www.mexnext.org). Amongst others, five papers relating to Task 29 research were presented at the Science of Making Torque conference in October 2016 [2-6].

3.0 Outcomes and Significance

Mexnext results have been made public, and numerous publications have presented the new aerodynamic insights and improved aerodynamic models. This work targets a considerable reduction of the uncertainty in design calculations.

Currently, wind turbine designers compensate for uncertainties with costly safety margins in order to avoid any risk of instability or failure should wind loads be higher than expected. Alternatively, if loads are lower than expected, turbines can be over dimensioned and result in more costly designs. Task 29 Mexnext's detailed aerodynamic measurements could unravel several hidden physical phenomena crucial to wind turbine operation. Information on the relevance of experiments for aerodynamic model improvements is in the long-term research agenda of the European Academy of Wind Energy [9].

4.0 Next Steps

Task 29 Mextnext participants will continue to study the differences between calculations and measurements at aligned conditions. Specifically, comparisons will be made at yawed conditions. Several areas have been defined for further aerodynamics research (e.g., standstill and IEC aerodynamics, dynamic inflow, and boundary layer transition). Acoustic measurements will be investigated in more detail as well. Ideas for a follow-up of phase of Mexnext are currently being discussed within the consortium.

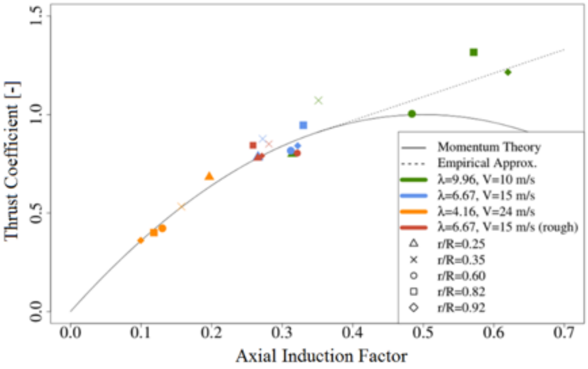

Figure 2. Axial force coefficient versus axial induction factor from New Mexico experiment

Table 1. Countries and Organizations Participating in Task 29 During 2016

Country/Sponsor	Organization(s)
CWEA	Chinese Wind Energy Association (CWEA)
Denmark	Technical University of Denmark (DTU)
France	EDF ONERA; IFP Energies nouvelles
Germany	Fraunhofer Institute for Wind Energy and Energy System Technology (IWES); University of Stuttgart (IAG); Kiel University of Applied Sciences; ForWind; Windnovation; German Aerospace Laboratory DLR Enercon
Japan	Mie University/National Institute of Advanced Industrial Science (Mie/AIST)
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)
Norway	Institute for Energy Technology, Norwegian University of Science and Technology (IFE/NTNU)
Spain	National Renewable Energy Centre of Spain (CENER)
Sweden	Uppsala University Campus Gotland
United States	National Renewable Energy Laboratory (NREL)
*Technion in Israel is observing Task 29	

New Mexico Experimental Data Aligns with Theoretical Calculations

In earlier phases of Task 29 Mexnext, the largest problem was the relation between loads and velocities, which did not seem to obey the momentum relation in the Mexico experiment. In the later New Mexico experiment, researchers carried out more reliable calibrations. Figure 2 shows the axial force coefficients versus induction factor at different radial positions and tip speed ratio.

The differences between momentum theory and experimental results are much smaller than they were in the old Mexico experiment. The remaining differences can be explained by radial dependency and by the turbulent wake state for axial induction factors larger than about 0.38. The results from CFD calculations, processed in a similar way, show comparable differences to momentum theory.

A detailed momentum analysis relating the loads and a full survey of the velocities from New Mexico shows consistent results on the momentum balance in axial and in-plane direction [4].

References:

Opening photo: New Mexico experiment smoke visualizations in Large Low-Speed Facility (LLF) (9.5 x 9.5 m^2) of German-Dutch Wind Tunnel (DNW) (Photo credit: T. Westra)

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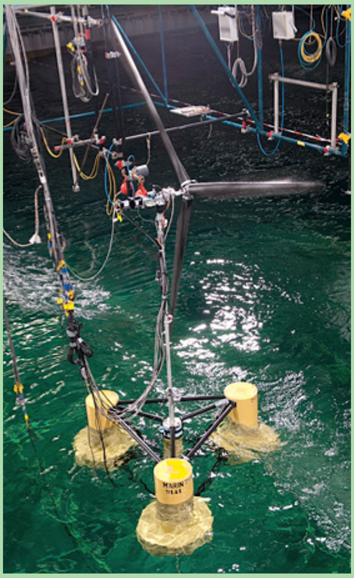
Task 30

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



1.0 Introduction

Offshore wind turbines are designed and analyzed using comprehensive simulation tools (or codes) that account for the coupled dynamics of the wind inflow, aerodynamics, elasticity, and controls of the turbine, along with the incident waves, sea current, hydrodynamics, mooring dynamics, and foundation dynamics of the support structure.

Previous IEA Wind TCP efforts to verify the accuracy of offshore wind turbine modeling tools through code-to-code comparisons included the OC3 and OC4 projects (Offshore Code Comparison Collaboration and Offshore Code Comparison Collaboration Continued). These projects were successful in showing the influence of different modeling approaches on the simulated response of offshore wind systems. However, code-to-code comparisons can only identify differences. They do not determine which solution is the most accurate.

To address this limitation, OC5 (Offshore Code Comparison Collaboration Continued, with Correlation) was initiated to validate offshore wind modeling tools through the comparison of simulated responses to physical response data from actual measurements. The project involves three phases and uses data from both floating and fixed-bottom systems, as well as both scaled tank testing and full-scale, open-ocean testing. The objectives of the Task 30 OC5 project are to:

- **Identify limitations of offshore wind design tools to accurately represent real-world behavior**
- **Make needed improvements to industry design tools**
- **Determine future research and development needs**
- **Train new analysts to run and apply the codes correctly**

2.0 Progress and Achievements

The work on OC5 Phase I was completed in 2015, and the results from the second dataset analyzed within this phase were published in 2016 [1]. Phase II was initiated in the summer of 2015, and was nearly complete by the end of 2016. A summary paper of the findings from this phase will be published in 2017 [2].

For Phase II, numerical models of the DeepCwind floating semisubmersible wind system were validated using measurement data from a 1/50th-scale test campaign performed at the MARIN offshore wave basin. Validation of the models was assessed by comparing the calculated ultimate and fatigue loads for eight different wave-only and combined wind/wave test cases against the measured data, after calibration was performed using free-decay, wind-only, and wave-only tests.

The results of this work show a decent estimation of both the ultimate and fatigue loads for the simulated results. However, there was fairly consistent underestimation, attributed to an underestimation of wave-excitation forces outside the linear wave-excitation region and the presence of broad-band frequency excitation in the experimental measurements from wind.

Participant results showed varied agreement with the experimental measurements based on the modeling approach used. Modeling attributes that enabled better agreement included:

- The use of a dynamic mooring model
- Wave stretching, second-order theory, or some other hydrodynamic modeling approach that excites frequencies outside the linear wave region
- Nonlinear wave kinematics models
- Unsteady aerodynamics models

The results also showed that a Morison-only hydrodynamic modeling approach, which employed long-wavelength approximation,

OC5: Comparing Modeling for Offshore Wind Systems

The results from this validation project show the advantages and disadvantages of different modeling approaches for computing the complex aero/hydro/servo/elastic loading and response of offshore wind systems. Figure 1 shows the frequency content of the tower base load, and provides evidence of the under-prediction in most of the models for the load at low frequencies (colored lines) compared to the experimental measurements (black line), as well as the over-estimation of the load at high frequencies for those using a Morison-only model (dashed colored lines).

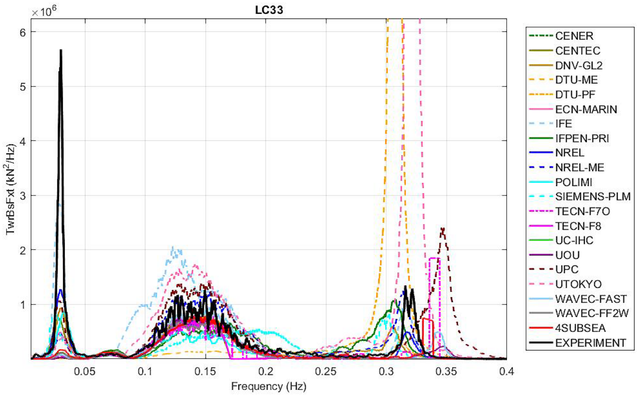


Figure 1. PSD of tower-base shear force for operational wave excitation, significant wave height of 7.1 m and peak period of 12.1 s

could create excessive pitch excitation and resulting tower loads at high frequency bands.

Phase III will start in 2017 and use open-ocean data obtained from Alpha Ventus—the first German offshore wind farm—for the validation. The wind farm consists of twelve 5-MW turbines. The validation work will employ a REpower 5M (currently Senvion) wind turbine placed atop a jacket support structure manufactured by OWEC Tower from Norway.

Table 1. Countries and Organizations Participating in Task 30 in 2016

Country/Sponsor	Organization(s)
CWEA	China General Certification Center; Goldwind; Dongfang Electric Corporation
Denmark	Technical University of Denmark (DTU) Wind Energy; DHI; DONG Energy; University of Aalborg
France	PRINCIPIA; EDF; INNOSEA; DCNS; Ideol; IFP Energies nouvelles
Germany	Fraunhofer Institute for Wind Energy and Energy System Technology (IWES); University of Stuttgart SWE; Senvion; Leibniz Universität Hannover; WindGuard Certification; Ramboll
Italy	Polytechnico Di Milano; Ricerca Sistema Energetico (RSE); University of Florence
Japan	University of Tokyo; WEIT; ClassNK
Korea	University of Ulsan; Jeju National University
Netherlands	Energy Research Centre of the Netherlands (ECN); The Knowledge Centre WMC; MARIN
Norway	Norwegian University of Science and Technology; Institute for Energy Technology; Marintek; 4Subsea; University of Stavanger; Simis
Portugal	Wave Energy Centre; EDP; CENTEC
Spain	ALSTOM Wind; National Renewable Energy Centre of Spain (CENER); IH Cantabria; Tecnalia; Siemens PLM; Universitat Politècnica de Catalunya
United Kingdom	DNV GL
United States	ABS Consulting; National Renewable Energy Laboratory(NREL); University of Maine; Penn State University; Texas A&M University

Since the start of the OC5 project, 148 participants from 68 organizations in 18 countries have participated in the Task. The organizations contributing to the project brought together expertise from both the offshore structure and wind energy communities, including designers, consultants, certifiers, developers, and research institutions.

3.0 Outcomes and Significance

The most significant outcomes of this project are the improvements to industry offshore wind design tools based on these findings. Other significant outcomes include training analysts to appropriately use these tools, improvement of offshore design processes, and a set of public benchmark problems that have been used for numerous additional research projects focused on improving offshore wind design, operations and maintenance (O&M), and lowering cost. Improvements to offshore wind industry's engineering tools and methods will enable the development of more optimized designs.

4.0 Next Steps

Phase III will continue through 2017 and will close out the OC5 project, with an anticipated end date in the middle of 2018. A potential extension is being discussed, and ideas include the use of higher-fidelity models to better understand the capabilities of engineering tools and to conduct tank tests to have the ability to address potential validation issues and assess uncertainties.

References:

Opening figure: Offshore Wind System Designs Examined in OC5: (a) Phase II: Semi – Tank Testing, (b) Phase III: Jacket – Open Ocean Test (Photo Credits: Andy Goupee, Univ. of Maine, 19576; Gary Norton, NREL, 27360)

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Authors: Amy Robertson, National Renewable Energy Laboratory, United States; and Wojciech Popko, Fraunhofer Institute for Wind Energy and Energy System Technology IWES, Germany.

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Task 30 Offshore Code Comparison Collaboration, Continued, with Correlation (OC5)

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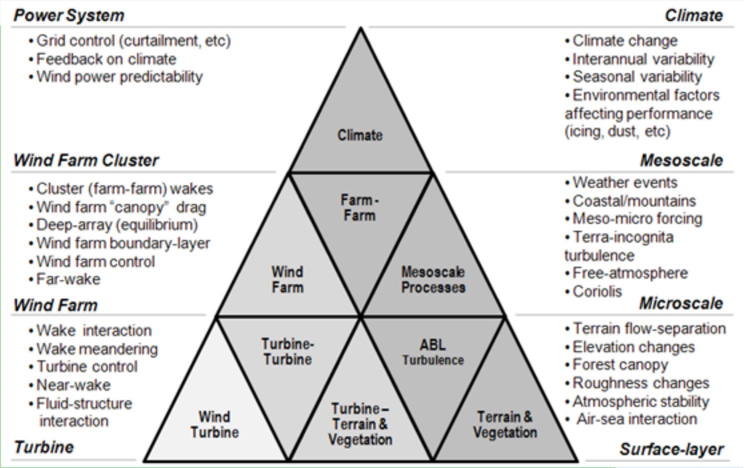
Task 31

WAKEBENCH: Benchmarking Wind Farm Flow Models



1.0 Introduction

Current wind energy models often lead to overprediction of wind plant performance, leading to high uncertainties and significant financial losses in the wind industry. State-of-the-art wind resource assessment and wind farm design techniques employ four main topics: characterization of large-scale climatology; mesoscale meteorological processes; microscale, terrain and wind farm array effects; and wind turbine aerodynamics [1]. Traditionally, these topics were analyzed separately, which gave rise to different independent research communities (meteorologists, wind engineers, aerodynamicists). As a result, a wide variety of models have been developed by each specialized group with little interaction with the neighboring communities.

The next generation of wind energy models will look for an integrated approach that can produce a more comprehensive characterization of the modeling system [2]. The objective of IEA Wind TCP Task 31 is to develop a verification and validation, and uncertainty quantification (VV&UQ) framework that will support a sustained improvement of wind farm models [6]. The task will employ a continuous evaluation process, simulating as many test cases as possible to gain confidence and credibility on the model results towards the intended use of the model and its range of applicability [7].

An overarching goal of this Task is to create a forum for international cooperation in wind energy flow modeling, where project participants can leverage results and data from parallel projects related to the topic, notably, from the New European Wind Atlas (NEWA) project and U.S. Department of Energy's 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.

2.0 Progress and Achievements

The second phase of Task 31 kicked off in June 2015 with 11 participating countries: China, Denmark, Finland, France, Germany, Japan, the Netherlands, Spain, Switzerland, Sweden, and the United States. In 2015, a Topical Expert Meeting on UQ for wind assessment was used to define new activities in the Task.

The GABLS3 benchmark has been studied in the context of meso-micro coupling methodologies to simulate a diurnal cycle at the Cabauw meteorological mast in the Netherlands [8]. More than ten participants are active in this benchmark, with meso and microscale models and different ways of interfacing.

The NEWA Ryningsnäs benchmark, led by Uppsala University, is looking at appropriate ways of modeling the flow above a heterogeneous canopy characterized with a lidar scan. In A2e, the meso-micro group is looking at transient episodes relevant for wind energy in the Texas Tech University 200 m tower at the Scaled Wind Farm Technology (SWiFT) facility. The OWA-Rødsand 2 experiment is being used to study array effects in large wind farms and their dependency on inflow conditions, homogeneous (open sea) or heterogeneous (coastal, near Nysted wind farm).

The Horns Rev test case was used by DTU to develop a formal UQ method for wind farm wake models. This will be complemented with experiments in Sandia N.L. scaled wind farm facility (SWiFT) on wake steering. Researchers have begun discussions with the IEC 61400-15 working group to seek collaboration around the assessment of UQ for wake losses.

3.0 Outcomes and Significance

By adopting a framework for model evaluation, Task 31 participants expect to facilitate the development of a better integrated model-chain covering all relevant scales for wind energy flow models. This framework will also enable a V&V integrated planning for wind farm performance by prioritizing experiments and simulations that can have the greatest impact in improving design tools.

Through benchmarking, researchers leverage data and share results from existing projects for wider exploitation in an international context. Industry can use this forum to test their design tools against state-of-the-art models and provide datasets that can be used to challenge those models.

4.0 Next Steps

The second version of the Model Evaluation Protocol (MEP) is being prepared to extend the scope to all relevant scales for wind farm flow models (opening figure). This building block-approach identifies relevant physical phenomena in the interplay between the atmospheric and the wind power systems. The new MEP will be discussed online in The Wind Vane, a new blog for researchers to share their insights and challenges to shape future activities in Task 31 Phase 3 [9].

References:

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

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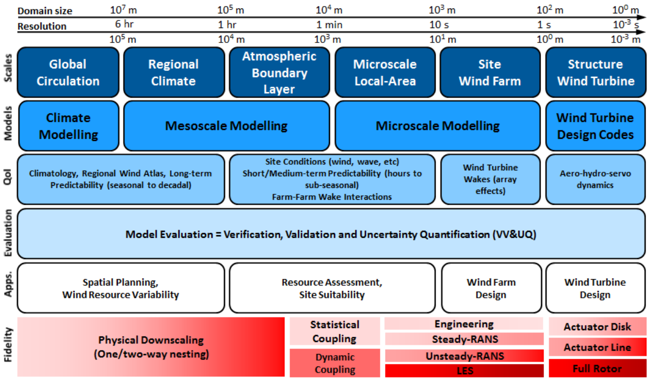

Figure 1: Mesoscale-to-microscale model chain in the Wakebench V&V framework. Source: Sanz Rodrigo J. et al. [2].

IEA Wind TCP Tasks 30, 31, and 32 Collaborate on Alpha Ventus

The Alpha Ventus case, led by ForWind, proposes to benchmark wake models to reproduce a single wake characterized with a doppler lidar system. Collaboration with IEA Wind TCP Task 30 OC5 will be pursued to simulate the offshore turbine response using aeroelastic codes.

Based on the analysis, turbine model specifications will be provided to IEA Wind TCP Task 31, so participants can study the coupling of fluid and structure to produce insights about the performance of the integrated system. The Alpha Ventus case was also discussed as part of a workshop with IEA Wind TCP Task 32 on lidar measurements for wake assessment and comparison with wake models in Munich, October 2016.

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Task Contact

Task 31 WAKEBENCH: Benchmarking Wind Farm Flow Models
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Table 1. Countries and Organizations Participating in Task 31 During 2016

Country/Sponsor	Organization(s)
CWEA	North China Electric Power University; Huaneng Clean Energy Research Institute; Goldwind; Envision
Denmark	Technical University of Denmark (DTU) Wind Energy; DONG Energy; VESTAS Wind and Site Competence Centre; EMD International A/S
Finland	VTT Technical Research Centre of Finland
France	EDF R&D; IFP Energies Nouvelles; Université du Havre; Meteodyn; Université d'Orléans
Germany	ForWind Oldenburg University; DEWI; SUZLON; German Aerospace Center
Japan	University of Tokyo; Wind Energy Institute of Tokyo
Netherlands	Energy Research Centre of the Netherlands (ECN); Technical University of Delft
Spain	National Renewable Energy Centre of Spain (CENER); EDP Renovaveis
Sweden	Upsala University
Switzerland	École Polytechnique Fédérale de Lausanne; Swiss Federal Institute of Technology
United States	National Renewable Energy Laboratory; Sandia National Laboratories; Cornell University; University of Wyoming; National Center for Atmospheric Research; Lawrence Livermore National Laboratory; University of Texas at Dallas; University of Colorado Boulder

Task 32

LIDAR: Wind Lidar Systems for Wind Energy Deployment

1.0 Introduction

Lidar technology provides a remote sensing alternative to traditional wind measurements techniques. The objective of IEA Wind TCP Task 32 is to identify and mitigate barriers to the use of lidar for the following applications: site assessment, power performance, loads and control, and complex flow.

Task 32 addresses these four application areas individually through workshops, since each technology is at a different readiness level. These workshops, along with the annual General Meeting, provide an international forum for industrial and academic partners to exchange new ideas, experiences, and measurement techniques for using lidar in wind energy. It is expected that the second Phase of Task 32 will further strengthen the international exchange of knowledge, experience, and ideas and will further foster the use of lidars in wind energy.

In total, 168 persons from 84 institutions and 17 countries (12 member countries, 5 interested countries) participated in the activities of Task 32 Phase 2 in 2016, including research centers, universities, wind measurement companies, and lidar and wind turbine manufacturers.

2.0 Progress and Achievements

In 2016, workshops were organized for each application area:

Workshop #1 on Floating Lidar Systems: Floating lidars were recently introduced as a cost-effective alternative to offshore met masts. Despite the rapid integration of floating lidar into offshore wind developments, not all challenges related to the application of floating lidar systems are fully identified and resolved yet. In February 2016, 32 participants from 11 countries worked on defining the current technology status and the requirements for improved maturity for floating lidar systems. As output of the workshop, participants prepared a presentation for the WindEurope Conference in September 2016 in Hamburg [1].

Workshop #2 on Optimizing Lidar Design for Wind Turbine Control Applications: One obstacle for lidar-assisted control of wind turbines is its multi- and interdisciplinary character. Since lidar and turbine manufacturers typically specialize in their own part of the puzzle, current lidar systems are not optimized for wind turbine control applications. In July, 33 participants from 9 countries worked on identifying the objectives of lidar-assisted control and barriers preventing the widespread use of lidars for control. The workshop provided a first step to bridge the gap between lidar manufacturers and wind turbine control engineers.

Workshop #3 on Lidar Wake Measurements: Recent studies suggest that lidar measurement could be included in the verification and validation process of wake models. These models are important for wind turbine and wind farm design as well as wind farm control. However, the use of the lidar technology in this field is hindered by different knowledge of lidar measurement limitations and wake models, as well as limited access to data. In October, 66 participants from 12 countries participated in a workshop featuring invited presentations about past and current measurement campaigns, a comparative exercise, and discussions about the objectives of lidar wake measurements and future cooperation.

Workshop #4 on Power Performance: Calculation of Uncertainty for Lidar Application: Both IEA Wind TCP Task 32 and the Power Curve Working Group identified the application of uncertainty guidelines from the upcoming edition of IEC 61400-12-1 (for power performance measurements) as a potential barrier. In December, 48 experts from 13 countries came together to evaluate the uncertainty methods for different configurations. A second round-robin workshop was completed in February of 2017 and a white paper will follow.

3.0 Outcomes and Significance

An IEA Wind TCP Recommended Practice on floating lidar systems is in development. The initial draft developed by task participants was published in February 2016 [2]. A more comprehensive draft was published at the end of 2016 with OWA funding [3].

In 2016, the following deliverables and outcomes were also achieved:

- Twelve Advisory Board meetings, including the kick-off meeting, were held to organize the workshops and General Meeting
- General Meeting held in Glasgow, December 2016
- New website launched: www.ieawindtask32.org
- Two newsletters distributed to more than 300 interested experts

Figure 1. Nature of barriers from four applications of the lidar technology in wind energy. Is additional research necessary or is the difficulty in the implementation?

Task 32 continues to provide an international open platform for the regular and continuous exchange of experience. Participants share progress from individual research activities and existing measurement projects on the performance of lidar devices and associated measurement techniques.

4.0 Next Steps

At least four workshops will be organized in 2017 based on the General Meeting outcomes and follow-up Advisory Board meetings. The following workshop topics are being considered:

- Wind resource assessment in complex terrain
- Power performance measurement using nacelle lidars
- Estimating turbulence with lidar
- Best practices for certification with Lidar-Assisted Control
- Elaboration of use cases
- Lidar uncertainty reduction

References:

Opening photo: Long range lidar measurements in complex terrain from a radio tower in the Swabian Alps in 2016 (Photo credit: SWE)

[1] Gottschall, et. al. (2016). *Floating Lidar Systems: Current Technology Status and Requirements for Improved Maturity.* Download from: www.ieawindtask32.org/download/task32documents

[2] Bischoff, O.; I. Würth, J. Gottschall, B. Gribben, J. Hughes, D. Stein, H. Verhoef (2016). *State-of-the-Art Report: Recommended Practices for Floating Lidar Systems*. Download from: www.ieawindtask32.org/

[3] Bischoff, O., J. Gottschall, B. Gribben, J. Hughes, D. Stein, H. Verhoef, I. Würth (2016). *OWA Floating LiDAR Recommended Practice.* Download from: www.carbontrust.com/resources/reports/technology/owa-floating-lidar-recommended-practice.

Identifying Barriers to Lidar Adoption for Wind Energy

To complement the Task's four workshops, the IEA Wind TCP Task 32 General Meeting is held annually to provide a forum to build community, report from previous workshops, and organize new ones. In December 2016, 48 participants from 14 countries joined the Task 32 General Meeting in Glasgow to identify lidar adoption barriers to address in the next year.

Small groups discussed new workshop topics for each application area, as well as an "out of the box" category to allow for topics that did not fit specifically in one of the application areas.

Discussions resulted in a comprehensive list of 18 topics that represent the community's opinion of the current status of research and how to mitigate barriers. This list will serve as a basis for the decision about workshop topics for 2017.

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Task 32 LIDAR: Wind Lidar Systems for Wind Energy Deployment
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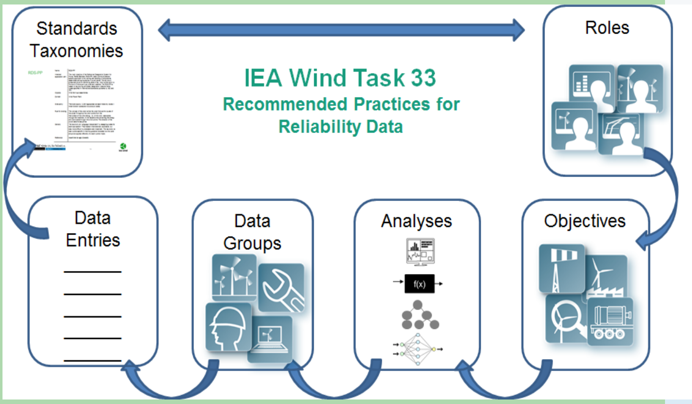
Table 1. Countries and Organizations Participating in Task 32 During 2016

Country/Sponsor	Organization(s)
Austria	Energiewerkstatt
Belgium	Engie Lab; Tractebel Engie
Canada	AXYS; TechnoCentre Éolien
CWEA	Envision; Goldwind; Huaneng Clean Energy Research Institute; MingYang
Denmark	DONG Energy; Technical University of Denmark (DTU) Wind Energy; Siemens; Suzlon; Wind Solutions
France	EDF; EOLFI; IFP Energie nouvelles; Leosphere; University of Orleans
Germany	Deutsche WindGuard; DEWI; DLR; DNV GL; ForWind, University of Oldenburg; Fraunhofer Institute for Wind Energy and Energy System Technology (IWES); GWU-Umwelttechnik; KIT Institute of Meteorology; Senvion; University of Stuttgart SWE; Wind-consult; Windtest Grevenbroich
Greece	Centre for Renewable Energy Sources (CRES)
Ireland	Bord na Móna; Mainstream Renewable Power
Japan	Advanced Industrial Science and Technology; Mitsubishi Electric Corporation; Wind Energy Institute of Tokyo
Korea	Jeju National University; Korea Testing Laboratory; Jeju Energy Corporation
Netherlands	Energy Research Centre of the Netherlands (ECN); Netherlands Enterprise Agency; TU Delft; Vattenfall
Norway	Christian Michelsen Research; Fugro
Spain	National Renewable Energy Centre of Spain (CENER); EOLOS Floating Lidar Solutions; Suzlon
Switzerland	Meteotest
United Kingdom	Babcock International Group; Carbon Trust;DNV GL; EDF Energy; Fraunhofer Centre for Applied Photonics; Frazer Nash; Mott MacDonald; Natural Power; NEL; Offshore Renewable Energy Catapult (ORE); RES; SgurrEnergy; SSE; University of Strathclyde; Wind Farm Analytics; ZephIR Lidar
United States	AWS Truepower; Business Network for Offshore Wind; Cornell University; DNV GL; E.ON; Envision Energy; GE; NREL; PNNL; Renewable NRG Systems; Sandia National Laboratories; Colorado School of Mines; Siemens; University of Colorado Boulder; University of Maryland; University of Wyoming; U.S. Department of Energy (DOE); V-Bar

Task 33

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

1.0 Introduction



Reliability is a critical issue for the growing wind energy industry since it affects other areas like safety, availability, maintenance, logistics and cost. Increasing future demands on the 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.

IEA Wind TCP Task 33 ran from 2012 through 2016 and focused on data collection from Supervisory Control And Data Automation (SCADA) systems, maintenance activities, and reliability issues during operation and maintenance. The objectives of Task 33 were to identify operator's demands, select the most appropriate statistical methods for providing key figures, and suggest which data to collect.

Testing and design optimization, specialized inspections like vibration measurements and frequency analyses, and safety issues of the structural components, as well as the connection of reliability data to real costs, were out of scope.

Task 33 concluded in 2016 with the publication of the IEA Wind TCP *Recommended Practice 17 Wind Farm Data Collection and Reliability Assessment for O&M Optimization* (IEA Wind RP17) in May 2017 [1]. The team consisted of experts from 11 countries with experience in data acquisition, reliability modeling, and data analysis from research and industry applications.

2.0 Progress and Achievements

Recommended Practice 17 leads the user to individually appropriate solutions for wind farm data collection and reliability assessment for O&M optimization (see opening figure). It is primarily directed at operators and service providers, but all identified stakeholder groups will benefit from the adoption of this best practice.

Several guidelines and standards from different industries provide lists of necessary data and values, as well as a range of taxonomies at varying degrees of granularity. However, none of these guidelines provide a complete scheme for reliability analyses of wind turbine components. The Recommended Practice presents an overview of appropriate standards and guidelines, suggesting taxonomies for categorizing component designations, measuring points, failure aspects, and maintenance tasks.

3.0 Outcomes and Significance

Historically, reliability data is rarely considered during the early stages of wind asset development and warranty-based operation by owners and operators. Their reliability ambitions range from 'comfortable with a complete reliance on third parties' (such as OEMs to manage asset reliability), to 'seeking control of maintenance strategies and actively managing asset reliability.'

While ambitious owner/operators strive to benchmark reliability metrics against those of their peers, this is often restricted by the unavailability and inconsistency of reliability data. From these key findings, IEA Wind TCP Task 33 participants derived the recommendations presented in Table 1.

The development and adoption of reliability data collection standards and reporting across the industry will take the time and commitment of all stakeholders. The value, as realized in other industries such as oil and gas, lies in safer, more effective, and more efficient maintenance policies, strategies and practices. Failure to do this will restrict the pace at which improvement opportunities for operations and maintenance costs can be identified and implemented.

4.0 Acknowledgements

The authors would like to thank all supporters of IEA Wind TCP Task 33. Nearly 40 people from 24 organizations in 11 member countries have regularly contributed to the RP. Numerous experts from the industry shared their knowledge in workshops and interviews. The IEA Wind TCP Executive Committee has always supported the team with valuable hints and comments.

Finally, many thanks are due to the IEA Wind TCP Secretariat, who helped the team in setting up and steering the whole project. Without this continuous support, the successful completion of the RP would not have been possible.

Table 1: Key Findings from *RP17: Wind Farm Data Collection and Reliability Assessment for O&M Optimization*

Developers, Owners, and Operators	**1. Make sure you get access to all relevant data** Consider reliability data to be of high value from the early stages of wind asset development. Ensure that access to reliability data and required data are factored into all contractual negotiations.
	2. Identify your use case and be aware of the resulting data needs Identify use cases linked to your organizational reliability ambitions and use these to define data collection requirements.
	3. Map all WT components to one taxonomy or designation system Map all wind asset components and maintenance activities to one of the taxonomies/designation systems identified in the IEA Wind *RP17*.
	4. Align operating states to IEC 61400-26 Align operating states with those specified in IEC 61400-26, the standard for a time- and production-based availability assessment for wind turbines [4].
	5. Train your staff to understand what data collection is helpful for All staff should be educated on the strategic significance of reliability data and empowered to improve related business processes and practices.
	6. Support data quality by making use of computerized means Whenever practical, seek to automate the data collection/collation process to reduce efforts and the risk of human error, as well as improving data quality.
	7. Share reliability data to achieve a broad statistical basis Engage in the external, industry-wide sharing of reliability and performance data to achieve statistically significant populations of data.
Development of Standards for the Wider Wind Industry	**8. Develop comprehensive wind-specific standard based on existing guidelines/standards** Develop a comprehensive wind specific standard based on ISO 14224, FGW ZEUS, and other existing guidelines/standard [2, 3].
	9. Develop component-/material-specific definition of faults, location, and severity As a longer-term recommendation, there is a need to develop standard definitions for damage classification and severity for structural integrity issues.

References:

Opening figure: The IEA Wind TCP Task 33 approach for developing Recommended Practice 17: from roles and objectives to data entries and standards/taxonomies (Source: IEA Wind TCP Task 33)

[1] Hahn B (Ed.), et al. (to be published 2017). *IEA Wind TCP Recommended Practices 17: Wind Farm Data Collection and Reliability Assessment for O&M Optimization.* Download from www.ieawind.org

[2] International Organization for Standardization (2016). *ISO 14224: Petroleum, petrochemical and natural gas industries -- Collection and exchange of reliability and maintenance data for equipment.*

[3] FGW e.V. (2106). *Technical Guidelines for Power Generating Units, Part 7*: "Maintenance of power plants for renewable energy, Category D2: State-Event-Cause Code for power generating units (ZEUS)."

[4] International Electrotechnical Commission. (2011/2014/2016). *IEC 61400-26*: Time-based (IEC 61400-26-1), production-based (IEC 61400-26-2) availability for wind turbine generating systems, (IEC TS 61400-26-3) Wind energy generation systems – Part 26-3: Availability for wind power stations.

Author: Berthold Hahn, Fraunhofer Institute for Wind Energy and Energy Systems Technology, Kassel, Germany.

Table 2. Countries and Organizations Participating in Task 33 During 2016

Country/Sponsor	Organization(s)
CWEA	Chinese Wind Energy Association (CWEA); Goldwind
Denmark	Technical University of Denmark (DTU) Wind Energy, University Aalborg
Finland	VTT Technical Research Centre of Finland
France	Maia Eolis
Germany	Fraunhofer Institute for Wind Energy and Energy System Technology (IWES)
Ireland	ServusNet
Netherlands	Delft University of Technology, Energy Research Centre of the Netherlands (ECN)
Norway	SINTEF Energy Research; NTNU University Trondheim
Sweden	Vattenfall Research and Development; Chalmers University Gothenburg
United Kingdom	Offshore Renewable Energy Catapult (ORE); ATKINS
United States	Sandia National Laboratories

Task 34

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

1.0 Introduction

Questions about the impact of wind energy on wildlife can result in challenges for project development. There continues to be a strong need to share lessons gained from field research, including management and monitoring methods, best practices, study results, and approaches to mitigate impacts and address cumulative effects of wind energy on wildlife.

The global nature of the wind industry—combined with the understanding that many affected species cross national boundaries and oceans—also points to the need for collaboration on an international level.

The objective of IEA Wind TCP Task 34, also known as WREN (Working Together to Resolve Environmental Effects of Wind Energy), is 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 wildlife challenges. The WREN strategy leverages the resources and expertise of member and nonmember countries and their extended networks to expand this knowledge base. Results include:

- **Development and publication of white papers that focus on and advance the understanding of issues of global concern within the wind community**
- **Continued enhancement of WREN Hub (WREN's web portal for collecting and disseminating publications and other information)**
- **Expansion of international collaboration and knowledge transfer**
- **Dissemination of scientifically based information and recommendations to a wide range of stakeholders**

2.0 Progress and Achievements

Task 34 activities fall into three categories: WREN Hub, white papers, and outreach, engagement, and information dissemination.

In addition to providing access to relevant literature and products developed within WREN, WREN Hub also provides information on key contacts, archives of webinars and online meetings, upcoming events, and other social media outreach forums as deemed appropriate. The functionality of the hub was also improved, including adding a tab on the Tethys website that provides direct access to WREN (Figure 1). Recent updates to WREN Hub include:

- Adding 160 wind-energy-relevant documents to the database
- Adding new filters and tags and improved site security
- Improving webpage response speed to under 5 seconds
- Completing the Tethys peer review

WREN members presented three posters and one oral presentation at the National Wind Coordinating Collaborative Research Meeting XI, as well as helped organize an international workshop.

Four webinars were held in 2016, all of which were recorded and posted on WREN Hub (Table 2). Progress was made on five white papers, including the *Adaptive Management White Paper* (published as an IEA Wind Technical Report) and a manuscript entitled Considerations for Upscaling Individual Effects of Wind Energy Development Towards Population-Level Impacts on Wildlife (submitted to Renewable and Sustainable Energy Reviews) [1].

WREN members are working on three other white papers: environmental risk-based management, cumulative impacts of wind energy on wildlife, and green versus green (balancing the local impacts of a wind facility on sensitive species against its global benefits, such as reduced carbon dioxide emissions).

Within each member country, efforts were taken to reach out to key stakeholders. As an example, Sweden disseminated information on the *Adaptive Management White Paper* through two newsletters, totaling 1,900 subscribers.

If you are new to Tethys, start here to learn more

Access thousands of publications and more, in a searchable database

Tethys Story

Making Wind Turbines Safer for Birds

Wind energy developers face challenges to gain public acceptance and necessary permits because of potential impacts on wildlife, especially birds and bats. As a result, developers may be required to monitor projects for the presence and abundance of both diurnal and nocturnal species, collect... **Read More**

Figure 1. New WREN Hub tab on the Tethys website that provides direct access to WREN (lower right) (source: https://tethys.pnnl.gov/)

3.0 Outcomes and Significance

In order for countries to meet policy objectives, including a decreased reliance on carbon-based energy sources, the concern regarding negative impacts from wind energy must be addressed.

WREN members have access to an expanded knowledge base and connections to others involved in:

1. Research on species and or habitat issues
2. Development and testing of mitigation strategies and technology solutions
3. Development and implementation of regulations and guidelines
4. Policy decisions that affect the advancement of wind energy deployment, among others

WREN uses multiple outreach tools to make information easily accessible to both WREN and non-WREN members and disseminate information to a wider range of stakeholders, including decision makers for proposed projects where species and habitat concerns may be problematic. The widespread dissemination of information is a key outcome of this Task.

Exploring a learning-based management approach for wind energy applications

The *Adaptive Management White Paper* was the culmination of an effort that began in 2014. As discussed in a two-page fact sheet entitled *Adaptive Management for Wind and Wildlife Interactions*, "Adaptive management (AM) is a learning-based management approach that is used to reduce scientific uncertainty, and has been applied to many types of development including filling of wetlands and various forms of renewable energy" [2]. However, AM has not been readily applied to wind energy projects.

This paper examines of the use of AM for wind energy, various policies and management principles, factors that have contributed to AM success stories or caused challenges, case studies that illustrate uses of AM (including bird and bat conservation plans), and discussions about the future use of AM for land-based and offshore wind development.

4.0 Next Steps

WREN members will continue to make progress on work package activities, including completing one or more of the white papers described above, continuing to enhance and expand WREN Hub, and focusing on outreach, engagement, and information dissemination.

Table 1. Countries Participating in Task 34 During 2016

Country/Sponsor	Organization(s)
France	Electricity of France
Ireland	BirdWatch Ireland
Netherlands	Rijkswaterstaat, Department of Water Quality
Norway	Norwegian Institute for Nature Research
Portugal	STRIX, Environment and Innovation
Spain	Spanish Council for Scientific Research
Sweden	Swedish Energy Agency; Vindval
Switzerland	Federal Department of the Environment, Transport, Energy and Communication; nateco AG
United Kingdom	Marine Scotland Science
United States	National Renewable Energy Laboratory (NREL); Pacific Northwest National Laboratory (PNNL); U.S. Department of Energy (DOE)

Table 2. WREN Webinar Participation and Downloads

Webinar Topic	Date	Attendees	Page Views
Monitoring Bat Activity Offshore	Mar. 1, 2016	76	1,169
Wind Energy Development Impacts on Marine Environment	Jun. 28, 2016	55	734
Assessing Marine and Avian Wildlife Off the New York Coast	Jul. 21, 2016	71	681
Adaptive Management in the Wind Energy Industry	Nov. 16, 2016	58	96

Two in-person meetings are planned in 2017: in Sweden in June and in Portugal in September. WREN will participate in the Conference of Wind energy and Wildlife impacts and will convene a workshop to reach out to the larger international community, seeking input for the three remaining white paper topics described earlier.

References:

Opening photo: Spirit, a 20-year-old bald eagle outfitted with a global positioning system logger, assisted with the collection of eagle flight pattern data for two different technology solutions under development that could ultimately be used at wind energy facilities to prevent eagle collisions with wind turbines. One solution includes radar; the other is a visual system. The research was a collaboration between the National Wind Technology Center at the National Renewable Energy Laboratory and others, including a wind industry company, a technology developer, and academia. (Photo credit: Lee Jay Fingersh, NREL)

[1] Hanna, L.; et. al. (2016). *Assessing Environmental Effects (WREN): Adaptive Management White Paper*. Berlin Institute of Technology, Bureau of Ocean Energy Management, Marine Scotland Science, Norwegian Institute for Nature Research, Pacific Northwest National Laboratory, and U.S. Department of Energy. pp 46. Download from: https://tethys.pnnl.gov/publications/assessing-environmental-effects-wren-white-paper-adaptive-management-wind-energy

[2] Copping, A. (2017). *Adaptive Management for Wind and Wildlife Interactions*. Download from: https://tethys.pnnl.gov/sites/default/files/publications/AM-White-Paper-Summary-final.pdf

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https://tethys.pnnl.gov/about-wren

Task 35

Full-Size Ground Testing for Wind Turbines and Their Components

1.0 Introduction

Prototype wind turbine field testing is the state of the art for design validation tests on a system level, but it is time consuming and expensive. As an alternative, full-size ground-based tests for validation of wind turbine designs have become attractive to the wind turbine industry because of lower commissioning effort and faster and more reproducible tests [1].

The goal of IEA Wind TCP Task 35 is to formulate recommendations for full-size ground test procedures for rotor blades and nacelles and to standardize them across the test facilities around the world. Depending on the configuration, test rigs should be capable of performing the same standardized test procedures with equivalent results at the same confidence level. As a long-term goal, the standardized test procedures should:

- **Advance the certification process**
- **Improve the quality and reliability of nacelles and rotor blades**
- **Optimize wind turbine design**
- **Reduce development time for wind turbines**
- **Support the evaluation of the in-field performance and possible failure modes of rotor blade and nacelle components**

2.0 Progress and Achievements

2.1 Nacelle subtask

The nacelle subtask defined several test procedures for full-size ground nacelle tests. To describe these test procedures, the nacelle subtask workgroup defined a framework for test load cases per the design load cases in the IEC 61400 standard. These test load cases are separated into three classes: operating mode, wind loads, and grid loads.

Wind loads include the wind profile model and the turbulence intensity model, and are used by the test rig to emulate the loads. Additional transient events or synthetic faults can be used. Grid loads represent the state of the grid connection and are imitated by the test rig's grid emulation system. The grid load cases include weak and strong grid conditions, model wind farm environments, and the potential application of synthetic faults like low voltage conditions.

Finally, these test load cases were used to describe the nacelle's test procedures by assigning the relevant test load cases to the corresponding test procedure. For example, conducting a mechanical robustness tests for a nacelle involves the operation of the nacelle with loads applied to the main shaft above nominal or rated conditions. Therefore, emulated wind loads should be calculated by extreme wind models, as well as extreme turbulence models. High load transient events, like extreme operating gusts, should also be considered, although a strong grid operation model is considered sufficient.

2.2 Blade subtask

Material testing and full-scale rotor blade testing has evolved with wind turbine rotor blade development. In virtually all mature industries, except wind turbine rotor blade manufacturing, intermediate-scale tests are the standard practice.

However, in 2016 the blade subtask developed a framework for defining and applying novel rotor blade subcomponent test methods. These new intermediate-scale tests allow a much deeper understanding of the effect of design changes before committing to large scale tests and serial production. Figure 1 shows the spectrum of possible structural tests, including the currently missing intermediate-scale testing of subcomponents.

3.0 Outcomes and Significance

Field testing of prototype wind turbines is a common technique used in the development of new products, but it is expensive, time-consuming, and suffers from the unpredictability of site-specific load cases. As an alternative, ground-based test rigs offer the opportunity to evaluate wind turbines and their components under reproducible conditions and may become an important tool for development and certification of new wind turbines.

Task 35 is developing guidelines for wind turbine rotor blade and nacelle testing on full-size ground test rigs. Rotor blade testing is included in the current version of the IEC 61400-23 standard, but due to the technical differences of rotor blade test rigs, the test results from different facilities may not be comparable. Therefore, the blade subtask is elaborating the differences between test procedures and test configurations to achieve uniform testing conditions for wind turbine rotor blades.

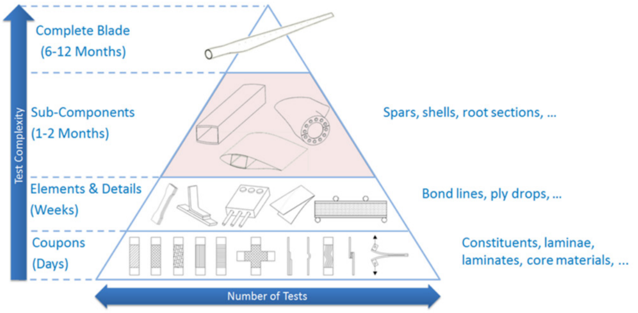

Figure 1. Test pyramid for wind turbine rotor blades (Source: Fraunhofer IWES)

4.0 Next Steps

In 2017, IEA Wind TCP Task 35 will continue preparing technical reports and recommendations for wind turbine nacelle and rotor blade tests on full-size ground test rigs.

References:

Opening figure: Collage of test centers participating in IEA Wind TCP Task 35

[1] Areva. (2011). "*Offshore wind turbines: AREVA's 5 Megawatt full load test bench in operation since October 2011*. Download from: www.areva.com/EN/news-9108/offshore-wind-turbines-arevas-5-megawatt-full-load-test-benchin-operationsinceoctober2011.html

[2] Bosse, D.; Jacobs, G.; Duda, T. (2016). "Capabilities of wind turbine ground test facilities – Benefits from standardizing test methods of blade and nacelle test center around the world"; in *Journal of fundamentals of renewable energy and applications*.

[3] Duda, T.; Jacobs, G.; Bosse, D. (2016). *IEA Wind TCP Task 35 – Full Size Ground Testing of Wind Turbine Nacelles*, presented at Wind Europe Summit 2016.. Download from: windeurope.org/summit2016/conference/programme/poster.php

[4] IEA Wind TCP Task 35 (2016). *Full Size Ground Testing for Wind Turbines and their Components Fact Sheets*. Download from www.cwd.rwth-aachen.de/iea-wind/.

Nacelle Testing Procedures Presented at the World Congress and Exhibition for Renewable Energy

IEA Wind TCP Task 35 nacelle subtask results were presented at the World Congress and Exhibition for Renewable Energy in Berlin. An abstract of the presentation was published in the *Journal of Fundamentals of Renewable Energy and Applications* [2]. The presentation included an overview of the international test centers for wind turbine nacelles and rotor blades, as well as a list of test rig functionality requirements and procedures for nacelle tests considered by the Task.

Test procedures include type certification testing per IEC 61400 standard and design validation tests (e.g. robustness tests with forced failures like pitch misalignments). Test rig requirements range from mechanical requirements, like torque excitation frequency and peak overload capabilities, to electrical requirements such as short circuit capabilities and grid conditions.

The presentation also provided an overview of the influences of abstraction from using emulated wind and grid loads on a nacelle test rig [3, 4].

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Task Contacts

Task 35 Full-Size Ground Testing for Wind Turbines and their Components

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Table 1. Countries and Organizations Participating in Task 35 During 2016

Country/Sponsor	Organization(s)
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
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
Germany	Siemens AG (Winergy); 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; Center for Wind Power Drives (CWD), RWTH Aachen University
United Kingdom	Offshore Renewable Energy Catapult (ORE); Lloyd's Register Group Services Ltd.
United States	National Renewable Energy Laboratory NREL, National Wind Technology Center; Clemson University Wind Drivetrain Test Facility; McNiff Light Industry; MTS Systems Corporation; Sandia National Laboratories
Netherlands (Observer)	Knowledge Centre Wind Turbine Materials and Constructions (WMC); We4Ce B.V.
Korea (Observer)	Korea Institute of Materials Science (KIMS)
Spain (Observer)	National Renewable Energy Centre (CENER); Ingeniería y Dirección de Obras y Montaje (IDOM)

Task 36

Forecasting for Wind Energy

1.0 Introduction

When power is traded in the markets, the required forecasting horizon is typically day-ahead and includes weather models alongside online data. As penetration levels increase, wind power forecasting depends on other inputs in addition to the weather models. These include algorithms that incorporate online data and non-weather related aspects into the forecasts. In this area, there are three distinct challenges:

IEA Wind TCP Task 36 focuses on improving the value of wind energy forecasts to the wind industry. These challenges are represented in the Task's three Work Packages. Work Package 1 aims to improve Numerical Weather Prediction (NWP) models and is led by Helmut Frank of Deutscher Wetterdienst and Will Shaw from the Pacific Northwest National Laboratory.

Work Package 2 analyzes the predictability and uncertainty of power forecasting models, and establishes a good practice for benchmarking. This section is led by Bri-Mathias Hodge and Caroline Draxl of the National Renewable Energy Laboratory, and Pierre Pinson and Jakob Messner of the Technical University of Denmark. Finally, Work Package 3 helps end-users optimize probabilistic forecast information and is led by Georges Kariniotakis of MINES ParisTech and Corinna Möhrlen of WEPROG.

2.0 Progress and Achievements

Results from Work Package 1 include a list of meteorological masts standing 100 m or greater, which can be used for verification of wind profiles and wind speeds [1]. This list includes location information as well as instructions on how to access online data for each tower.

A list of meteorological field campaigns is also available on the Task website [1]. The main contributions come from the Wind Forecast Improvement Project (WFIP 2) in the Columbia River Gorge in the United States, as well as the New European Wind Atlas (NEWA) 2017 campaign in Perdigão, Portugal. Additional activities include placing a lidar on a ferry traversing the Baltic Sea and the near-shore RUNE experiment in Jutland, Denmark. Task participants prepared ten oral presentations and a poster for the Special Session on the American Meteorology Society Annual Meeting in Seattle, United States in January 2017 [2].

Work Package 3 investigates how stakeholders presently use probabilistic forecasting to develop guidelines for the industry. Task participants created questionnaires and conducted structured interviews on the use of forecast uncertainties in the power sector.

For the survey, five categories of end users were identified: System Operator, Trader, R&D, Energy Service Organizations, and Power Producers/Managers [3].

Thus far, 88% of those surveyed are active in the day-ahead market, while 58% also use the intra-day, and only 29% use the reserves market. Respondents use forecasts for wind and solar power on almost equal terms. Situational awareness with assistance from uncertainty forecasts was only used by 14%. While all interviewees agreed that probabilistic forecasting is well known, almost none are using it actively in their business practices. The first evaluation of these results was presented in a conference paper [4].

3.0 Outcomes and Significance

The IEA Wind TCP Task 36 on Forecasting is the largest global group combining meteorologists, researchers, operational forecasters, and end users.

Task participants are preparing an IEA Wind TCP Recommended Practice on how to set up a benchmarking process, with guidance on which error measures to use. The report will be reviewed by commercial forecasters and end users, to ensure that it benefits both groups. The same applies to a state of the art report for the use of uncertainty forecasting in the power industry.

Figure 1. The participants of the workshop on future research issues in Barcelona, 9 June 2016. (Photo Credit: Gregor Giebel)

Solar forecasting works with similar methods to wind forecasting, often with experts in both areas in the same company. For this reason, Task 36 plans to collaborate with the upcoming IEA PV Task on Solar Forecasting.

4.0 Next Steps

IEA Wind TCP Task 36 will continue moving forward on several deliverables:

- Organize the Technology Workshop on Forecasting at the Wind Energy Science Conference 2017 in June in Denmark, previously organized by WindEurope [6]
- Circulate the first draft of the benchmarking and forecast trialling Recommended Practice amongst participants
- Collaborate on a paper regarding wind power forecast communication and guidelines to identify, evaluate and select uncertainty forecasts
- Distribute second versions of tall towers overview of meteorological experiments lists, as well as links to existing benchmarking data sets

References:

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

Table 1. Countries and Organizations Participating in Task 36 During 2016

Country/Sponsor	Organization(s)
Austria	ZAMG
CWEA	CEPRI; China Meteorological Administration; Envision; North China Electric Power University; Xinjiang Goldwind; Zhejiang Windey
Denmark	Technical University of Denmark (DTU); Danish Meteorological Institute (DMI); DNV GL; ENFOR; WEPROG; Energinet.dk; Vestas; Vattenfall; ConWX
Germany	DWD; Fraunhofer Institute for Wind Energy and Energy System Technology (IWES); ForWind; ZSW; WindForS; EWC; Stuttgart University; Enercon; Tennet
France	MINES ParisTech; MeteoSwift; EDF; CNR; Engie Green
Finland	VTT Technical Research Centre of Finland; Vaisala
Ireland	Dublin Institute of Technology; University College Dublin
Norway	NORCOWE; Kjeller Vindtekknik
Portugal	INESC TEC; Prewind; Smartwatt; Laboratório Nacional de Energia e Geologia (LNEG)
Spain	Vortex; Iberdrola Renovables; EDP Renovaveis
Sweden	Vattenfall
United Kingdom	MetOffice; Reading University; UK National Grid
United States	U.S. Department of Energy; Pacific Northwest National Laboratory (PNNL); National Renewable Energy Laboratory (NREL); National Oceanic and Atmospheric Administration; National Center for Atmospheric Research; EPRI; MESO, Inc. UNC Charlotte

Task Participants Develop Wind Energy Forecasting Research Priorities

A main highlight of 2016 was the published list of wind energy forecasting research issues, developed during a public workshop in Barcelona in June 2016 [5]. Task participants classified the list into "Low Hanging Fruit," "Follow the Development Initiated by Others," and "Research Needed."

Low Hanging Fruit: An increase in temporal resolution is high on the industry wish list, the industy is moving to 10-minute or even 5-min resolution.

Initiated by Others: At the public workshop, industry representatives asked for an increase in spatial resolution. However, literature on the topic indicates that the increased variability might worsen the traditional error scores.

Research Needed: Data assimilation was on top of the list. Using turbines to yield meteorological data in a region where few observations exist (i.e., at hub height, especially offshore) would conceptually improve the initial state of the NWP model. However, data quality for the turbine is a major issue. Short-range ensembles. These could potentially yield a meteorologically sound spread intra-day, though the first results still depend on calibration to get enough spread.

Finally, researchers need to improve model physics by thoroughly looking inside the meteorological models to improve calculation of stability and its daily pattern, low level jets, and a nowcast for difficult situations (i.e., thunderstorms, small low pressure systems, or other issues).

[1] www.ieawindforecasting.dk

[2] https://ams.confex.com/ams/97Annual/webprogram/8ENERGY.html

[3] www.ieawindforecasting.dk/News/Nyhed?id=6270327C-6ADD-4128-AC04-823BF6031C01

[4] Möhrlen, C., Bessa, R. J., Barthod, M., Goretti, G., Siefert, M. (2016). *Use of Forecast Uncertainties in the Power Sector: State-of-the–Art of Business Practices*. Proc. of the 15th Int. Workshop on Large-Scale Integration of Wind Power into Power Systems, as well as on Transmission Networks for Offshore Wind Farms, Vienna, 15-17 November 2016. Download at: http://download.weprog.com/WIW16-211_MOEHRLEN-ET-AL_ONLINE-VERSION.pdf

[5] Giebel, G., et. al. (2016). "Wind Power Forecasting: IEA Wind Task 36 & future research issues." *Journal of Physics:* Conference Series 753, 032042. doi:10.1088/1742-6596/753/3/032042.

[6] www.wesc2017.org

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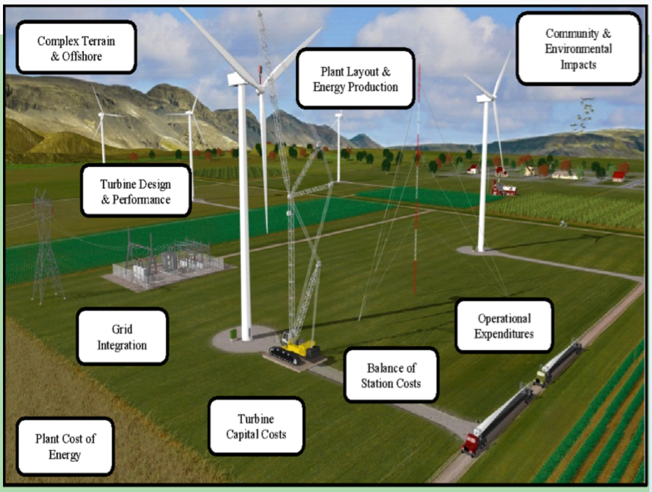
Task 37

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



1.0 Introduction

Over the last few decades, wind energy has evolved into an 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 also imposes more requirements on the technology in terms of performance, reliability, and cost.

To address these changing expectations, industry has made efforts to improve the performance, reliability, and cost of turbine and plant design. However, trade-offs amongst competing goals require a more integrated approach. The purpose of IEA Wind TCP 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 improve overall system performance and reduce the levelized cost of energy. There are significant challenges to developing such integrated approaches, both within and across organizations. Opportunities and challenges must be explored to apply systems engineering across the entire wind energy system. This approach can be applied to the tools and methods used in wind plant research, design, and development.

2.0 Progress and Achievements

The objective of Task 37 is to improve the practice and application of systems engineering to wind energy research, design, and development (R,D&D). In 2016, Task participants began developing guidelines for a common framework for integrated R,D&D at different fidelity levels, reference wind energy systems, and benchmarks for multidisciplinary design analysis and optimization (MDAO) activities at different system levels. Each of these areas looked at both turbines and plants.

The primary focus for Work Package 1 was to catalog and identify analysis and design tools along with their associated disciplines and fidelities. The preliminary result of the effort was a catalogue of existing MDAO toolsets for wind turbine and plant design. The catalog will be published online and updated as the toolsets evolve and new ones are introduced.

The secondary result was the development of a series of discipline/fidelity matrices categorizing different models within these toolsets. The matrices are the first step in the larger effort to develop a common framework modeled after a successful aerospace research initiative [1].

Once the discipline/fidelity matrices were completed, the team performed a cross-walk to identify the most common fidelity for each discipline used by wind industry MDAO researchers and practitioners. Figure 1 illustrates one example of a matrix and cross-walk for the rotor. A publication on the effort is forthcoming in 2017.

Developing reference turbines that reflect current technology in the wind industry is the focus of the Work Package 2. Two reference turbines are under development: a low-wind-speed land-based 3.X MW machine, and a redesign of the DTU 10 MW offshore machine.

In 2016, industry was surveyed to establish the high-level specifications for each machine (rotor diameter, specific power, drivetrain configuration, etc.) and draft versions of the model were created. These draft models will undergo a more detailed industry review in 2017. Reference turbine survey results and detailed design specifications for each turbine will be published in 2017.

Planning for Work Package 3 began in 2016, but no activities will take place until 2017.

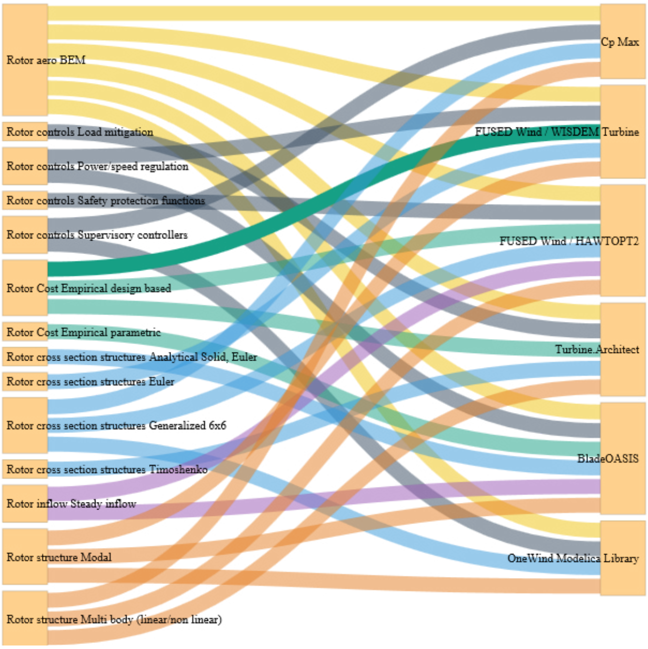


Figure 1. Rotor multidisciplinary design analysis and optimization (MDAO) a) discipline/fidelity matrix and b) cross-walk with toolset catalogue

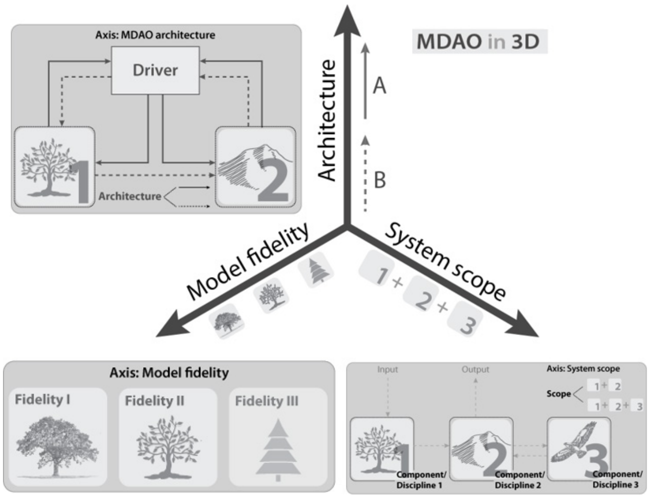


Figure 2. Wind turbine and plant multidisciplinary design analysis and optimization (MDAO) problem formulation dimensions [2]

3.0 Outcomes and Significance

The IEA Wind TCP Task 37 completed its first year of activities in 2016. As each Work Package progresses, publications are expected to increase and improve MDAO practice for wind energy applications within the larger research and industry community.

4.0 Next Steps

Several outcomes are expected in 2017 including the release of draft guidelines for wind turbine and plant system modeling frameworks, detailed design specifications for the new reference turbines, and the results of the first MDAO case studies for wind turbines.

In addition, Task participants will start looking at wind plants in 2017. The reference plants will use newly developed reference turbines and MDAO plant case studies to leverage developments of the reference plant.

Table 1. Countries and Organizations Participating in Task 37 During 2016

Country/Sponsor	Organization(s)
Denmark	Technical University of Denmark (DTU) Wind Energy; Vestas Wind System A/S; Siemens Wind Power
Germany	Fraunhofer Institute for Wind Energy and Energy System Technology (IWES); Technische Universitat at Munchen; University of Stuttgart; Nordex Energy GmbH
Netherlands	Energy Research Centre of the Netherlands (ECN) Wind Energy; Delft University of Technology; DNV GL
Norway	SINTEF Energy Research; Christian Michelsen Research; Uni Research
Spain	National Renewable Energy Centre of Spain (CENER)
United Kingdom	BVG Associates Ltd.; DNV GL; Offshore Renewable Energy Catapult (ORE)
United States	National Renewable Energy Laboratory (NREL); Brigham Young University; Siemens Wind Power; GE Global Research; Sandia National Laboratories; University of Texas at Dallas

Multidisciplinary Design Analysis and Optimization (MDAO) Research Needs for Wind Energy Applications

A key activity in 2016 was the development and publication of a conference paper on MDAO research needs at The Science of Making Torque from Wind 2016 Conference [2].

Figure 2 is a key graphic from the paper published in the journal series for the conference. The graphic illustrates the different dimensions of applying MDAO to wind energy applications. The system scope (bottom right of the figure) addresses the number of disciplines involved in a single integrated design process (whether that happens in an integrated or sequential approach).

A given design process may integrate multiple disciplines together at varying levels of fidelity—even including multiple fidelities of a single discipline. The last axis (top left) looks at the MDAO architecture (or workflow). A particular design process may organize the workflow in a variety of ways using endless combinations of models and fidelities in sequential, integrated, or even multi-level approaches.

The complexity of the overall design process can increase along any of the three dimensions of scope, fidelity, and architectures. As the IEA Wind TCP Task 37 moves forward, a key outcome will be to explore each of these dimensions in terms of their impacts on design outcomes for wind turbine and plant applications.

References:

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

[1] Böhnke, D., Nagel, B., and Gollnick, V. (2011). "An approach to multi-fidelity in conceptual aircraft design in distributed design environments." *2011 Aerospace Conference*, Big Sky, MT, 2011, pp. 1-10. doi: 10.1109/AERO.2011.5747542

[2] Sanchez Perez-Moreno, S., Zaaijer, M. B., Bottasso, C. L., Dykes, K., Merz, K.O., Réthoré, P.-E., and Zahle, F. (2016) "Roadmap to the multidisciplinary design analysis and optimisation of wind energy systems." *J. Phys.: Conf. Ser. 753 062011.* doi:10.1088/1742-6596/753/6/062011

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Task 39

Quiet Wind Turbine Technology

1.0 Introduction

Societal acceptance of new technologies is key to their successful adoption. In some jurisdictions, there is concern about the potential impact of wind turbine noise. Noise pollution from technology affects all of us and it is important to ensure that people are not exposed to excessive levels. Wind turbines are no different. We set out to consolidate understanding of wind turbine sound emissions.

The goal of IEA Wind TCP Task 39 is to accelerate the development and deployment of quiet wind turbine technology. The task will convene an international expert panel to exchange learning, identify and report best practices in the measurement and assessment of noise, and develop an IEA Wind Recommended Practice contributing to the ongoing development of IEC standards for wind turbine noise.

2.0 Progress and Achievements

IEA Wind TCP Task 39 was approved for a three-year phase in December 2016. Denmark, Finland, Ireland, and Sweden have provisionally agreed to participate in this new task with many others expressing interest. Additional participants are very welcome.

The Task's kick-off meeting will be held later in 2017 for participants to finalize plans for the coming phase. The collaboration will carry out its work in a series of focused work packages.

Work Package 1 addresses interdisciplinary education and guidance. This work package will support interdisciplinary discussion. The aim is to form a consensus with robust, scientific, widely accepted and transparent metrics for wind turbine sound and noise.

Noise is not only—or even primarily—an engineering problem. Work Package 2 seeks to understand the various aspects of technical noise. Task participants will refine the focus of this Work Package during their semi-annual meetings. Some potential topics already identified include:

- Measurement and Data Analysis
- Modeling
- Wind turbine design
- Human response to wind turbine noise
- Physiological effects
- Psychological effects
- Public engagement
- Shared resources

Finally, Work Package 3 involves the development of a Recommended Practice for Task 39. The Task Coordinator and Work Packager Leaders will form a working group to develop this document, which will integrate and summarize the findings of the previous Work Packages. Participants will update this Recommended Practice over the course of the Task to ensure that those accessing it read the most current information.

3.0 Outcomes and Significance

A primary aim is to ensure that the best information is used to build relevant international standards and government regulations. This will help stakeholders at every level. An additional industry perspective is that the wind turbine supply market is international and not local. Yet despite this global market, there are a wide range of national noise limits and approaches to the overall wind turbine noise assessment process. The diversity of local noise regulations can bring unwarranted compliance costs and confound progressive technical advances to develop wind turbines with lower noise impact.

By identifying best practices in an international collaboration, Task 39 hopes to improve regulations and standards and to reduce unnecessary complication, increasing the effectiveness of quiet wind turbine technology.

4.0 Next Steps

The kick off meeting for IEA Wind TCP Task 39 will be held later in 2017. At this time, the Task is accepting countries and organizations who want to participate in the Task.

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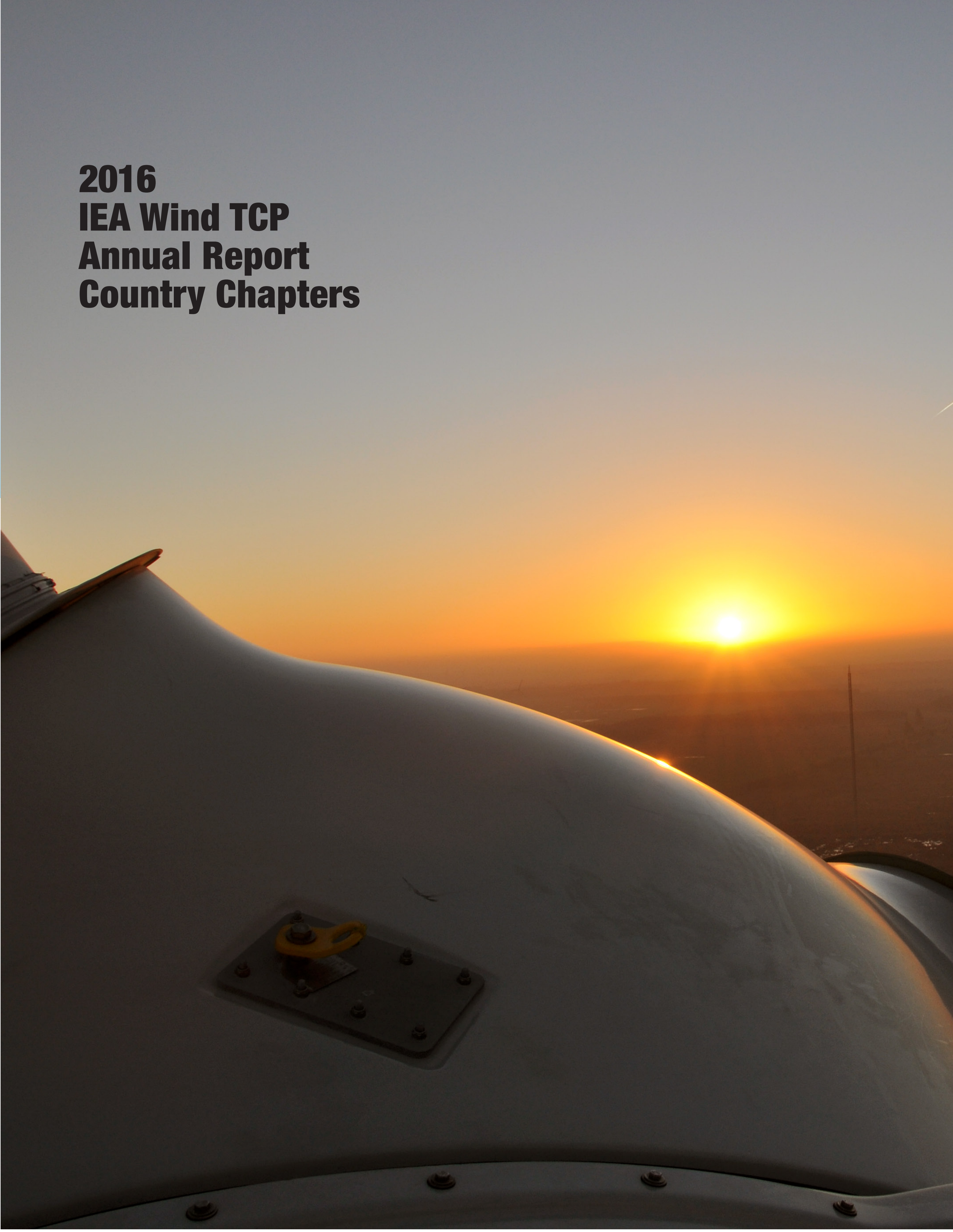
2016
IEA Wind TCP
Annual Report
Country Chapters



Austria

1.0 Introduction

Austria is among the global leaders in renewable energy, with nearly 70% renewables in its electricity mix. The natural conditions in Austria—hydropower, biomass, and a high wind energy potential—have allowed for this development. However, installation rates are currently decreasing due to political uncertainties.

In 2016, Austria installed 75 turbines with a capacity of 228 MW, compared to 108 turbines (319 MW) in 2015. By the end of 2016, more than 2,600 MW were installed in Austria. This capacity is able to produce 5.7 TWh, which accounts for 9.3% of the country's electricity consumption. The government's official capacity target is 3,000 MW per the Green Electricity Act (GEA) 2012. The feasible potential is estimated at 6.6 GW (17.7 TWh) by 2030.

2.0 National Objectives

Wind power installations significantly proliferated following the 2012 Ökostromgesetz (Green Electricity Act, GEA). This law established a 2020 target of 2,000 MW added wind power capacity over 2010 levels (1,011 MW). The law also upheld the existing feed-in-tariff (FIT) system. An ordinance by the Minister for Economic Affairs set the FIT, rather than the GEA itself; however, the FIT decreases automatically by 1% if not determined each year.

The tariff for 2016 was 0.0904 EUR/kWh (0.0952 USD/kWh). For 2017, it was fixed at 0.0895 EUR/kWh (0.0942 USD/kWh).

The market price collapse significantly lowered the annual budget for green electricity. This has created a project queue, with projects waiting as long as 2025 for new funding. A small amendment to the GEA 2012 could lower the pressure and political uncertainty by allocating a 1.42 billion EUR (1.50 billion USD) investment to install the 260 turbines (850 MW) that have already been approved.

2.1 Targets

The GEA 2012 preserved the existing targets: 15% of renewable energy supply without large hydro and 1,700 MW total wind power capacity by 2015. Austria reached the 2015 GEA target in the first quarter of 2014.

The GEA 2012 also established a long-term target of adding 2,000 MW of wind power capacity by 2020 (a total of 3,000 MW by 2020). This is higher than Austria's wind energy target in its National Renewable Energy Action Plan (NREAP). Austria set a target of 1,951 MW by 2015 and 2,578 MW by 2020 in the NREAP (per European Union directive 2009/28/EC).

In a 2014 study, the Austrian consultant Energiewerkstatt estimated that by 2020, Austria could achieve a total wind power capacity of 3,808 MW (annual production of 9 TWh), as well as a total capacity of 6,649 MW by 2030 (annual production of 17.7 TWh) [1].

2.2 Policies supporting development

The 2002 GEA triggered investments in wind energy from 2003–2006 (Figure 1). An amendment in 2006 created uncertainty among green electricity producers and restricted project development. This led to nearly four years of stagnation in Austria's wind power market. A small amendment to the GEA in 2009 and a new FIT in 2010 (0.097 EUR/kWh; 0.102 USD/kWh) improved the situation.

In July 2011, parliament adopted new legislation for electricity from renewable energy sources: the GEA 2012. This retained the existing FIT system, but established a stable legal framework through 2020 for the first time. However, there are still restrictions for new projects; projects only get a purchase obligation and a FIT if they 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 contracts with green electricity producers are limited to the available funds for new projects – a budget that started

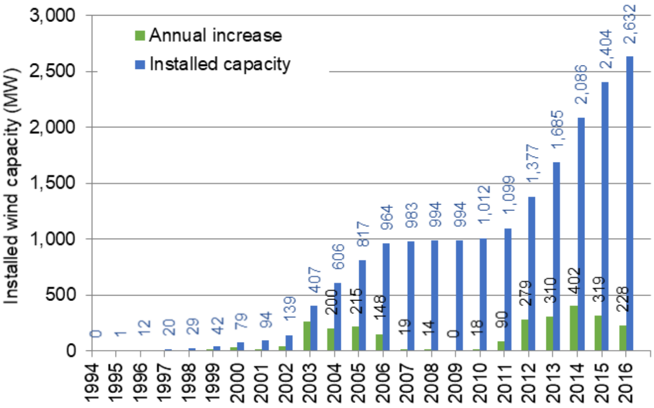


Figure 1. Wind power capacity in Austria from 1994–2017

with 50.0 million EUR/yr (52.7 million USD/yr). This is enough for approximately 120–350 MW of new wind capacity per year depending on the market price for electricity and the applications from photovoltaics and small hydro power plants. The budget decreases by 1.0 million EUR/yr (1.05 million USD/yr) for the first ten years.

The FIT is still set by an ordinance and is not fixed in the GEA 2012. The FITs are fixed in the Ökostromverordnung/Green Electricity Regulation by the Minister of Economic Affairs in accordance with the Minister of Environment and the Minister of Social Affairs. Tariffs are guaranteed for 13 years, and the purchase obligation is limited to a specific amount of capacity (depending on the available funds for new projects). The tariff for 2016 was set 0.0904 EUR/kWh (0.0952 USD/kWh) and will be 0.0895 EUR/kWh (0.0942 USD/kWh) in 2017.

3.0 Implementation and Deployment

On average, more than 527 million EUR (500 million USD) were invested annually from 2012-2016. Wind power was the fourth largest industry investment during this period. The current waiting queue would free investments of 1.6 billion EUR (1.5 billion USD), create 5,100 wind industry jobs, and raise the wind share to nearly 15% of electricity consumption.

Wind power currently has the highest acceptance rate of all electricity production technologies in Austria. The acceptance rate has been approximately 80% for the past four years. Given the concentration of wind energy in the eastern part of Austria, the approval rate is especially high (92–96%) in this region.

3.1 Progress

The rate of wind power installations increased significantly in 2012 (Figure 1). By the end of 2013, Austria had installed 1,685 MW of wind capacity with an estimated annual rate of 3.6 TWh of electricity production. One year later, the capacity increased to 2,086 MW, with 4.5 TWh of electricity production, 7.2% of the Austrian electricity demand. New installations reached 319 MW in 2015, leading to a cumulative installed capacity of 2,404 MW (8.7% of electricity consumption). The 2015 installed capacity produced more than 5.2 TWh/yr.

Wind electricity avoids 3.4 million tons of CO_2 emissions every year. With a capacity of 2,632 MW in 2016, the annual production of all Austrian wind turbines accounts for 9.6% of the Austrian electricity demand and avoids approximately 3.7 million tons of CO_2. The estimated capacity for the end of 2017 is 2,818 MW.

Most wind turbines are installed in Lower Austria (1,412 MW), followed by Burgenland (997 MW), Styria (168 MW), Upper Austria (47 MW), Vienna (7 MW), and Carinthia (1 MW) (Table 2).

3.2 Operational details

Enercon and Vestas are the dominant wind turbine suppliers in Austria (Figure 2). Most of the nation's turbines have a capacity of 1.8–2.3 MW. Since 2013, more than 80% of new installations are 3-MW turbines or larger, leading to an average size of 3.1 MW for newly installed capacity. 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 2016, the tallest turbines were the 203-m Vestas V126 in lower Austria.

Austria installed 75 turbines in 2016 for a total installed power capcity of 2,600 MW; 5.7 TWh of wind-generated electricty accounted for 9.3% of the country's electricity consumption that year.

3.3 Matters affecting growth and work to remove barriers

The crucial points for wind power growth are FIT amounts, the stability of the incentive program, and annual project funding. The FIT has determined wind power growth since the GEA 2012 was implemented. Because the tariffs are fixed for two years, some stability is guaranteed. However, growing demands from the grid providers and rapidly expanding installation costs have constrained growth.

Other issues include rising project development costs and growing burdens from ancillary services, which rose from 89 million EUR (94

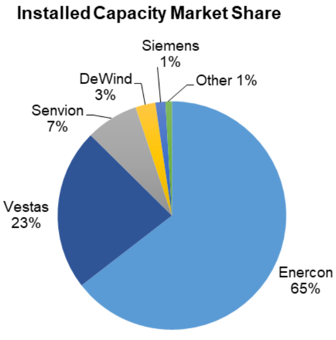


Figure 2. Turbine supplier market share by installed capcity

Table 1. Key National Statistics 2016: Austria	
Total (net) installed wind power capacity	2,632 MW
Total offshore capacity	0 MW
New wind power capacity installed	228 MW
Decommissioned capacity	---
Total electrical energy output from wind	5.7 TWh
Wind-generated electricity as percent of national electricity demand	9.3%
Average national capacity factor	25%
Target	3 GW
National wind energy R&D budget	N/A

Table 2. Capacity and Number of Turbines by Federal State

Federal State	Capacity	Turbines
Lower Austria	1,412 MW	654
Burgenland	997 MW	416
Styria	168 MW	81
Upper Austria	47 MW	30
Vienna	7 MW	9
Carinthia	1 MW	1
Austria	**2,632 MW**	**1,191**

million USD) in 2011 to more than 200 million EUR (211 million USD) in 2014. Rising costs are mainly the result of market failure.

Unlike most of Europe, power producers in Austria bear a major share of the ancillary cost ("g-component"), which decreases competitiveness. These factors combined with the collapsed market price to significantly lower the annual budget for green electricity. This resulted in a project queue, wherein projects may wait until 2025 for new funding.

A small amendment to the GEA 2012 could reduce the pressure and political uncertainty. By early 2017, the amendment stalled in the political process. This delayed project development on 260 wind turbines (850 MW) and an investment amount of 1.6 billion EUR (1.5 billion USD). Since those projects have already been approved by the legal authorities, significant investors might be frustrated. Without an amendment, the net installed capacity will decrease in the coming years.

4.0 Impact of Wind Energy

4.1 Economic benefits

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 2015 (the latest year with statistics available), the annual turnover of existing wind parks operators was over 320 million EUR (337 million USD).

Austria's wind energy industry includes more than 178 supplier and service companies. These companies are industry leaders in the fields of conducting, wind power generators, wind turbine generator design, and high-tech materials. Local companies are successful in both the land-based and the offshore sectors. Moreover, Austrian service providers, such as crane companies, planning offices, and software designers, work intensively abroad. Many wind energy operators have expanded abroad to implement their know-how on a global level.

According to a study conducted by the Austrian Wind Energy Association, one-third of the Austrian industry in the wind energy supply chain obtains an export volume of more than 750 million EUR (790 million USD). This is evidenced by between 20–25% of their turnover. Table 3 reflects the costs of new wind energy projects.

4.2 Industry development

Cooperatives and private companies own 60% of Austria's existing wind turbines, while the other 40% are owned by utilities. When the first wind turbines in Austria were built in 1994, cooperatives or single wind turbines built by farmers were most common. Utilities and other companies entered the market in 2000 and 2003, after a stable framework in the support system was established.

Austrian operators are very active with neighboring countries in Central and Eastern Europe, and some independent companies have also started businesses outside Europe. There are no major wind turbine manufacturers in Austria, though 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 supplies generators for the global market. There are also several global players with wind competence centers in Austria, such as SKF. There has been an increase of small and medium enterprises entering the market in recent years, largely due to the growth of the domestic market.

Start-ups have also emerged in the wind energy industry. For example, start-up company Eologix implemented an innovative ice detection system on rotor blades after working in the radio frequency identification sector. Due to the economic structure of the Austrian industry, there is a significant potential for high quality products on the software, service, and component sector, which is partially transferred from the automotive and aerospace industry.

5.0 R,D&D Activities

5.1 National R,D&D priorities

In Austria, several national R,D&D projects focus on the challenges of wind energy in cold climates. The "R.Ice" project launched in April 2016, which aims to elaborate on an icing map of Austria and observe icing events at wind turbines with an innovative imaging method.

Table 3. Cost of New Wind Energy Projects

	EUR/kW	USD/kW
Total investment costs	1,715.00	2,077.00
Turbine costs	1,390.00	1,683.00
Incidental costs (planning, connection to grid and grid reinforcement, etc.)	325.00	394.00
O&M costs average	0.02	0.03

Project "Ice.Control" investigates the possibilities of meteorological prognosis for icing events on wind turbines.

Austria is also currently carrying out two national research projects on small wind turbines. The "Urban Small Wind Power Project" addresses the challenges of installation and operation of small wind turbines in urban, highly-turbulent areas. The project "SmallWP@Home" investigates the flow conditions over different roof shapes.

5.2 Collaborative research

In 2009, Austria joined the IEA Wind TCP Task 19 Wind Energy in Cold Climates. The previous term continued until end of 2015, during which the Austrian participants carried out a detailed comparison of different ice detection systems. Each partner country also evaluated their country's legislative requirements for assessing the risk of falling ice fragments from wind turbines.

In the current term, Austria is leading a subtask which aims to prepare a set of guidelines and recommendations regarding the ice risk assessments. Furthermore, the Vestas blade heating system will be evaluated for two winter seasons.

In 2013, Austria joined the IEA Wind TCP Task 27 Small Wind Turbines in High Turbulence Sites. Since 2016, Austria has been participating in Task 32 LIDAR: Lidar Systems for Wind Energy Deployment. The cooperation will continue until the end of February 2019.

6.0 Next Term

Currently, The GEA 2012 does not provide the necessary incentives to develop wind energy in Austria to its full potential. It also harms investment security, as it will expire before the queued wind energy projects are fully installed. Overall, the political risk has risen massively in 2016, and the situation for wind isn't likely to improve in 2017.

References:

Opening photo: Oberzeiring wind park, Austria (Photo credit:)

[1] Energiewerkstatt. www.energiewerkstatt.org

Author: Florian Maringer, Austrian Wind Energy Association and Andreas Krenn, Energiewerkstatt, Austria.

Belgium

1.0 Introduction

The federal government began the first Belgian offshore wind park in the North Sea in 2003, and in 2004 created a 156-km^2 area in the Belgian exclusive economic zone in international waters for wind parks. The first wind turbines were installed in this area in 2009. At the end of 2016, 182 offshore wind turbines were operational—producing 2,390 TWh/yr and providing electricity for approximately 670,000 families. This was slightly lower than 2015 due to a decrease in wind resources.

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 offshore wind power. For example, the test zone for the Alstom-Haliade 150 6-MW offshore turbine demonstrates how Belgium's offshore zones are perfect for research purposes.

2.0 National Objectives

In general, Belgium's renewable energy policy is aligned with the EU 2020 targets. The land-based and offshore wind energy developments are essential for the Belgian and European targets for energy development from renewable sources. For 2020, Belgium has a binding national target for renewable energy equal to 13% of the gross final consumption of energy (Figure 1).

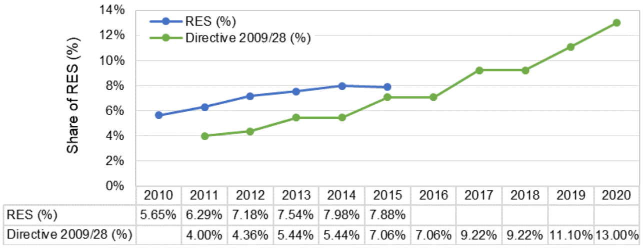
2.1 Targets

By 2020, the total land-based installed capacity in Belgium should reach 3,000 MW, and an additional 2,292 MW is planned offshore for a possible total of 5,292 MW of wind power. Offshore wind alone will already account for 10% of the electricity demand and 8.5 TWh of electricity by 2020.

2.2 Policies supporting development

Regarding offshore wind power, the transmission system operator (TSO), Elia, is obligated to buy green certificates from generators at a minimum price set by federal legislation. This system was established in 2002 and was amended in 2014 and 2016. Purchase agreements must be approved by the regulator, CREG, and purchase obligations apply for a period of 22 years, but may not exceed the depreciation period.

Belgium introduced changes to the levelized cost of wind energy (LCOE) based formula to address the risk of overcompensation. Following the amendment, LCOE levels will be fixed by the Energy Minister for each beneficiary separately based on a proposal from the CREG. So far, prices have been fixed for two parks: Norther at 124.00 EUR (130.57 USD) and Rentel at 129.80 EUR (136.68 USD).



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
RES (%)	5.65%	6.29%	7.18%	7.54%	7.98%	7.88%					
Directive 2009/28 (%)		4.00%	4.36%	5.44%	5.44%	7.06%	7.06%	9.22%	9.22%	11.10%	13.00%

Figure 1. Percent of renewable energy share in Belgium's gross final consumption [1]

3.0 Implementation and Deployment

3.1 Progress

Offshore wind electricity generation was first installed in 2009 and progressed rapidly to a total of 712 MW in 2016. The Belgian government is working quickly to reach the 2020 targets, although some social acceptance problems with a land-based connection caused delays in 2015 and 2016 (Table 2). This matter was resolved and offshore installation is expected to increase in 2017.

Land-based wind capacity remained low until 2004 when the installed capacity and production started to double year after year from 96 MW in 2004 to 1,548 MW in 2016. Land-based wind is on track to reach its 2020 objectives after much progress during the last few years (Table 2).

3.2 Operational details

The rated capacity of installed turbines has increased sharply for offshore and land-based wind. Table 4 shows the operational status of all the offshore wind parks in Belgium; the same data is unavailable for land-based wind parks.

3.3 Matters affecting growth and work to remove barriers

Work to remove barriers to new wind energy projects continues. Such barriers include spatial planning limitations (i.e., 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. Such legal cases could potentially 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 parks both in the Flemish and Wallonia regions. Belgium has limited space for wind energy compared to many other countries. However, the relatively high offshore wind resources provide the most potential, according to an IEA in-depth review in 2015.

4.0 Impact of Wind Energy

4.1 Environmental impact

In addition to adding sustainable energy capacity, offshore wind energy developments also increase biodiversity, specifically corals, plants, etc. in the sea. Offshore wind turbine foundations form artificial reefs, where mussels and other sea life grow. The foundations also contribute to the growing fish population, providing many opportunities to further develop the marine culture in the Belgian North Sea.

More than 2,200 MW are estimated to be installed in offshore areas by 2020, representing more than 8.50 TWh without CO_2 emissions, and fulfilling 10% of the national electricity demand.

4.2 Economic benefits

The wind energy sector creates excellent opportunities on the economic level. Being active in this industry has also created opportunities for export. In addition to wind park constructions, there is a need to build grid infrastructure, grid connections, and connections with neighboring countries.

The impact on employment is substantial and 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. The offshore wind industry supports about 15,000 jobs in Belgium including export activities, construction and operations and maintenance. More specifically, the offshore wind industry will continue to provide significant direct and indirect contributions to the energy sector—which has about 50,000 direct jobs today (Figure 2) [1].

4.3 Industry development

Belgium's wind industry includes:

- 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:
- Operators such as OWI-lab, VJI, Laborelec.

5.0 R,D&D Activities

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

5.1 National R,D&D priorities

Several key technologies that Belgium wants to invest in for the future have been put forward via the Steering Group of the SET-Plan.

With some research projects, like GREDOR or SmartWater in the Walloon Region, 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.

At the end of 2016, 182 offshore wind turbines were operational—producing 2,390 TWh/yr and providing electricity for approximately 670,000 Belgian families.

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, CG Power Systems, GeoSea-DEME, and ZF Wind Power (formerly Hansen Transmissions). These companies worked 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 project's academic research, in close collaboration with the other local universities.

5.2 R&D budget

Offshore and land-based wind are key areas supported by Belgium. In total, the Belgian government invested 4.30 million EUR (4.53 million USD) in 2015 in R&D. This is a constant rise in comparison with the previous years; for example, Belgium invested 4.01 million EUR (4.22 million USD) in 2014. Land-based wind investments in R,D&D are highly volatile. Support mechanisms for research in the energy sector are on an equal footing with other areas of research, following a clearly defined and established principle of competition.

In addition, the Department of Energy and Sustainable Building of the Walloon Region encourages the implementation of research projects in the energy sector. Their annual budget proposals allocate approximately 1.0 million EUR (1.1 million USD) that can be 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.

Table 1. Key National Statistics 2016: Belgium

Total (net) installed wind power capacity	2,260 MW
Total offshore capacity	712 MW
New wind power capacity installed	84 MW
Decommissioned capacity	0 MW
Total electrical energy output from wind	5.191 TWh
Wind-generated electricity as percent of national electricity demand	6.24%
Average national capacity factor	26.22%
Target	13% of renewables by 2020 in final gross energy consumption
National wind energy R&D budget	4.36 million EUR; 4.59 million USD (2015)

Table 2. Wind Power Capacity and Production [1]

	2009	2010	2011	2012	2013	2014	2015	2016
Offshore Wind Capacity and Production								
Offshore power capacity (MW)	32	197	197	381	708	708	712	712
Offshore electricity production (GW)	0.082	0.190	0.709	0.854	1.540	2.216	2.613	2.390
Capacity factor (%)	29.7%	11.0%	41.2%	25.6%	24.8%	35.8%	41.9%	38.3%
Total Electricity Production								
Total electricity production (GW)	91.235	95.189	90.241	82.923	83.526	72.687	70.648	83.133
Wind-generated electricity (GW)	0.996	1.292	2.312	2.751	3.687	4.614	5.574	5.191
Electricity demand met by wind energy (%)	1.09%	1.36%	2.56%	3.32%	4.41%	6.35%	7.89%	6.24%

Table 3. Operational Status of Belgian Offshore Wind Parks [1]

Project (Location)	No. of Turbines	Capacity (MW)	Area (km^2)[a]	Water Depth (m)	From Shore (km)
C-Power (Thorntonbank)	54	325	13.7–18.1	12–27.5	27
Belwind (Bligh Bank)	56	171	15.8	25–50	46
Nobelwind (Bligh Bank)	50	165	19.8	26–38	47
Northwind (Eldepasco) (Lodewijk-bank)	72	216	16.9	16–29	37
Norther (S. of Thorntonbank)	44	369.6	38	20–35	21
Rentel (N. of Thorntonbank)	48	312	23.16-27.3	22–36	31
Seastar (S. of Bligh Bank)	41–62	246	18.4	20–25	41
Mermaid (N. of Bligh Bank)	27–41	232–266[b]	28.4[c]	25–50	54
NorthWester (Bligh Bank)	22–32	217–224	28.4[c]	25–40	51
Totals	**414–459**	**2,254–2,295**	**238.5**		

[a] Total Area (without security zone)
[b] +20 MW wave energy
[c] Mermaid and Northwester together are 28.4 km^2

5.3 Test facilities and demonstration projects

OWI-lab climatic test facility focuses on offshore wind R&D [3]. This lab invested 5.5 million EUR (5.8 million USD) in state of the art testing 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 and maintenance research

The cold climate wind tunnel test facility (CWT-1 facility) at the Von Karman Institute (VKI) is a low-speed, closed-circuit wind tunnel capable of operating at subfreezing temperatures [4].

The OCAS test facility has a unique fatigue testing technique. This testing ensures the improved fatigue life of welded jacket connections, which can help decrease the cost of offshore wind by optimizing the design of jacket foundations [5].

5.4 Collaborative research

International collaboration is considered essential to accelerate the needed investments in research and development in renewable energy, such as in wind. To that end, the Federal Public Service of Economy became a member of the IEA Wind Technology Collaboration Program in 2015.

In 2016, Sirris, on behalf of Belgium, participated in Task 19 Wind Energy in Cold Climates. As part of the cooperative research Task, Sirris and OWI-lab co-authored two studies last year. Task 19 is also collaborating on a European level with the creation of the EERA Joint Program 'Cold Climate', led by Belgium with BERA.

Another international collaboration program is the North Seas region countries initiative. This is an initiative for the development of offshore wind energy to ensure a sustainable, secure, and affordable energy supply in the North Seas countries. This will facilitate the building of missing electricity links, allow more trading of energy, and further integrate energy markets. Reinforcing regional cooperation will help reduce greenhouse gas emissions and enhance security of supply in the region.

Nine Ministers signed the initiative (Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, and Sweden), as well as Vice-President for Energy Union Maroš Šefcovic, and Commissioner for Climate Action and Energy Miguel Arias Cañete.

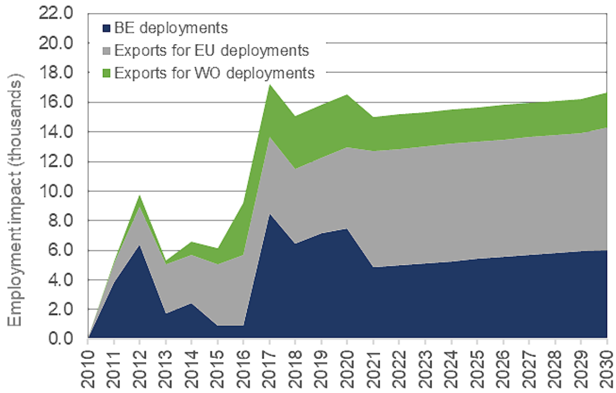


Figure 2. Total employment impacts from deployment in Belgium (BE), in Europe (EU), and in the rest of the world (WO) including construction and operations, both direct and indirect impacts [2]

6.0 Next Term

The offshore wind parks Rentel, Norther, Seastar, Mermaid, and Northwester 2 are fully approved by all planning bodies and will account for another 1,283 to 1,428 MW offshore capacity by the end of 2019.

References:

Opening photo: Nobelwind windfarm located in the Belwind concession area in the North Sea approximately 47 km from shore (Source: Nobelwind, http://nobelwind.eu/)

[1] Energy Observatorium, Federal Public Service of Economy

[2] Climact (2017). *Socio-Economische impact van de Belgische Offshore Windindustrie*. Download from: www.belgianoffshoreplatform.be/files/2017-03/1490865058_bop-socio-economic-impact-offshore-wind-rapport-nl.pdf

[3] Megavind, OWI-lab: http://megavind.windpower.org/megavind/test___demonstration_facilities/dynamic_list_of_global_test_facilities/owi-lab.html

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Canada

1.0 Introduction

In 2016, Canada added 681 MW of wind power capacity (net), an increase of 6.1% over 2015, to reach a total of 11,898 MW. This capacity was installed in Ontario (413 MW), Quebec (249 MW), and Nova Scotia (40 MW). Of the 21 new wind projects, 16 included significant ownership stakes from Aboriginal Peoples, municipal corporations, or local owners—an increase from the 15 out of 23 projects with community ownership in 2015.

Western Canada continues to show the strongest potential for growth in the near term. Alberta set a target of 30% renewable electricity generation by 2030, while Saskatchewan set a target of 50% renewable energy capacity by 2030. These provinces plan to procure approximately 5,000 MW and 2,000 MW of renewable power capacity by 2030, respectively, a significant portion of which is expected to be met by wind.

With wind becoming increasingly cost competitive, request for proposal (RFP) is expected to remain the preferred method of procurement.

2.0 National Objectives

There are currently no national targets for wind energy; however, the federal government continues to develop policies to address climate and energy commitments.

2.1 Targets

The federal government plans to reduce Canada's greenhouse gas (GHG) emissions 30% below 2005 levels by 2030, largely by phasing out traditional coal-fired power. Electricity supplied by non-emitting sources nationally will be brought up to 90% by that date, from the current 79%. Additionally, the government has committed to meet 100% of its power needs through renewable sources by 2025.

Several provinces have implemented targets for renewable electricity generation: Alberta (30% by 2030), New Brunswick (40% by 2020), Nova Scotia (40% by 2020), and Quebec (25% increase by 2030). Saskatchewan has a capacity-based, rather than generation-based, target of 50% renewable energy capacity by 2030.

2.2 Policies supporting development

In October 2016, the federal government announced a pan-Canadian carbon pricing plan, which requires all provinces and territories to have some form of carbon pricing by 2018. The floor price for carbon was set at 10.00 CAD/metric ton (7.07 EUR/metric ton; 7.44 USD/metric ton) for 2018, rising to 50.00 CAD/metric ton (35.35 EUR/metric ton; 37.20 USD/metric ton) by 2022.

Regionally, the government of Quebec released its Energy Policy 2030 in April 2016. This policy calls for a 25% increase in total renewable electricity production by 2030 and a reduction in oil and gas consumption of 40%. They will also allow wind power projects to supply export markets for the first time.

The Alberta government announced in November that it would launch a competitive process for 400 MW of new renewable electricity in 2017 as part of a larger plan to add 5,000 MW over the next 15 years. Alberta plans to retire all coal-fired generators ahead of the 2030 deadline targeted by the federal government. Saskatchewan plans to add up to 2,000 MW of renewable power capacity over this time frame, with an initial RFP for up to 200 MW expected in 2017.

3.0 Implementation and Deployment

Installed wind power capacity increased 20-fold over the past decade–a growth rate faster than any other electricity generating source in Canada [1]. Twenty-one projects were completed in 2016, representing 703 MW of new installed capacity and an investment of approximately 1.50 billion CAD (1.06 billion EUR; 1.12 billion USD).

3.1 Progress

Total wind power capacity now stands at 11,898 GW. In 2016, approximately 32.3 TWh of electricity were generated from wind, representing roughly 5.6% of national electricity demand.

3.2 Operational details

The trend towards larger turbines continued in 2016, many projects featured turbines with nameplate capacities of 3 MW or higher, including:

Figure1. Enercon E-101 3 MW turbines in the Niagara Region Wind Farm, Ontario, Canada (Source: © Enercon Canada Inc.)

- ENERCON Canada's 230-MW Niagara Region Wind Farm in Ontario featuring 77 ENERCON E-101 3-MW turbines (Figure 1)
- Pattern Energy's 184.6-MW Meikle Wind project in British Columbia, utilizing 26 GE 2.75 MW-120 and 35 GE 3.2 MW-103 turbines
- EDF EN Canada's 224.4-MW Nicolas Riou wind project in Quebec, comprising 65 Vestas 3.45-MW turbines with 110-m rotor diameter.

Capital costs for recent projects typically ranged from 1.9–2.3 million CAD/MW (1.3–1.7 million EUR/MW; 1.41–1.71 million USD/MW) for projects greater than 100 MW, and 3.0–5.0 million CAD/MW (2.1–3.5 million EUR/MW; 2.2–1.3 million USD/MW) for smaller projects.

3.3 Matters affecting growth and work to remove barriers

Low growth of energy demand contributed to the slow rate of wind power development in 2016. In September, the second round of the Ontario Large Renewable Procurement (LRP II) process—which represents 1,000 MW of renewable energy, including 600 MW of wind energy—was suspended, partly due to a weak outlook for electricity demand growth. Lack of a market for utility-scale wind in British Columbia contributed to the withdrawal of two projects totaling 550 MW from the province's environmental approval process.

The provinces and federal government are taking steps to remove uncertainty around the national energy and emissions strategy, exemplified by the carbon pricing policy and the *Pan-Canadian Framework on Clean Growth and Climate Change* announced in December 2016 [2,3].

The *Framework* includes plans for continued development of clean electricity systems, ensuring the greater use of renewable generation. It also states goals for electrification of the transport sector and increasing electricity transmission within Canada and to North America, all of which point to future growth in the wind industry.

Nova Scotia-based Emera Inc. announced a call for 900 MW of clean energy to supply a proposed transmission line feeding states in the northeastern United States, set to be in service in 2022. This transmission project is an indication of the increasing future demand for non-emitting electricity generation as these new policies are put in place.

4.0 Impact of Wind Energy

4.1 Environmental impact

In 2013, the electricity sector in Canada accounted for 85 million metric tons (MMT) of CO_2 equivalents [4]. The *Pan-Canadian Wind Integration Study* identified avoidable GHG emissions in Canada and the United States through additional Canadian wind energy penetration [5]. Relative to the 5% business as usual case, which most closely resembles the current level of wind penetration, additional annual reductions of 17 MMT of CO_2 equivalents in Canada, and 22.7 MMT in the United States, could be achieved under a 20% penetration scenario. Annual reductions of 32.3 MMT and 46.5 MMT could be achieved by the respective countries under a 35% penetration scenario.

4.2 Economic benefits

Permanent operation and maintenance jobs created for recent large projects (greater than 100 MW) have ranged from four to eighteen full-time equivalent (FTE) positions, or an average of 0.04-0.10 FTEs/MW of installed capacity. Peak construction jobs for large projects have typically numbered 300-500.

A 2015 analysis of the economic impacts of Ontario's wind energy procurement showed that, over the period 2013-2019, Ontario's wind procurement program will generate 41,500 direct and indirect FTEs, 3.1 billion CAD (2.2 billion EUR; 2.3 billion USD) in salary and wage compensation, and 9.5 billion CAD (6.7 billion EUR; 7.1 billion USD) in investments [6].

While nacelle components are typically imported, towers and blades are often produced locally, helping to spur new local manufacturing capability. The new ENERCON manufacturing facility in Port Weller, Ontario produced concrete towers for the 230-MW Niagara Region wind farm. Blades for the 179-MW Armow wind power project and the 100-MW Cedar Point II wind project were fabricated in Tillsonburg, Ontario. LM Wind Power's Gaspé factory provided blades for the 74.8 MW Roncevaux wind farm in Quebec.

A 2013 study on the economic benefits of the wind energy sector in Quebec showed that 3,300 MW of wind projects contracted since 1998 yielded investments of 5.8 billion CAD (4.1 billion EUR; 4.3 billion USD), of which 3.5 billion CAD (2.5 billion EUR; 2.6 billion USD) was deployed within the province [7]. The Quebec wind industry has supported an estimated 5,000 jobs/yr, with an average annual salary of 48,140 CAD (34,035 EUR; 35,816 USD), roughly 30% higher than the provincial average.

"Community Vibrancy" payments, or benefits paid directly to the local community over the lifetime of the project, are becoming increasingly common. The Armow wind power project committed 13.0 million CAD (9.2 million EUR; 9.7 million USD) in benefits over 20 years to the municipality of Kincardine, Ontario. The municipality of Frampton, in Quebec, will receive average annual revenue over 500,000 CAD (353,500 EUR; 362,000 USD) from the 24-MW Frampton community wind farm over the next 20 years.

4.3 Industry development

Sixteen of the 21 new projects in 2016 included significant ownership stakes from Aboriginal Peoples, municipal corporations, or local owners. A few examples are:

- The 150-MW Mesgi'g Ugju's'n wind farm, located in Quebec, is the largest First Nations-owned wind farm in Canada. The project includes 46 Senvion 3.2M114 turbines equipped with anti-icing mechanisms.

Table 1. Key National Statistics 2016: Canada

Total (net) installed wind power capacity	11,898 MW
Total offshore capacity	0 MW
New wind power capacity installed	703 MW
Decommissioned capacity	21 MW
Total electrical energy output from wind	32.3 TWh
Wind-generated electricity as percent of national electricity demand	5.6%
Average national capacity factor	31%
Target	N/A
National wind energy R&D budget	4.597 million CAD (3.250 million EUR; 3.420 million USD)

Installed wind power capacity increased 20-fold over the past decade—a growth rate faster than any other electricity generating source in Canada.

- The 100-MW Grand Bend wind farm in Ontario, where the Aamjiwnaang First Nation and the Bkejwanong Territory (Walpole Island First Nation) has 50% equity interest and Northland Power has the remainder.

Alberta-based wind developer Wind Power Inc. and renewable energy project developer Rocky Mountain Power Inc. entered into an agreement for energy storage services aimed at enhancing the economics of wind power in Alberta's often volatile electricity spot market. The proposed system will use wind-generated electricity to compress air and store it underground in salt caverns, and then release it during periods of low wind or when market prices are high.

Cape Breton University opened its own wind farm in May, becoming the first energy self-sufficient campus in North America. The three-turbine, 5.4-MW project generates 2.1 million CAD (1.5 million EUR; 1.6 million USD) in annual revenue under a 20-year contract through Nova Scotia's community feed-in tariff program.

5.0 R,D&D Activities

5.1 National R,D&D priorities

In 2016, the government of Canada announced the 25.0 million CAD (17.7 million EUR; 18.6 million USD) Clean Energy Innovation Program. The program will accelerate clean technology research and development in strategic priority areas of renewable energy, smart grids, and storage. Several projects were funded to demonstrate the integration of wind energy in both grid-tied and remote off-grid applications.

5.2 R&D budget

The national R,D&D budget for wind energy in 2016–2017 was 4.6 million CAD (3.3 million EUR; 3.4 million USD), an increase over the 3.2 million CAD (2.3 million EUR; 2.4 million USD) reported in 2015. The TechnoCentre Éolien (TCE) will receive 4.6 million CAD (3.3 million EUR; 3.4 million USD) for research on the intelligent integration of renewable energy and storage technologies in microgrids from 2016 to 2021.

Figure 2. Turbine under construction, Piikani Nation, Alberta, Canada (Photo credit Jaq Murillo)

5.3 Research results

In 2016, Canada continued to collaborate with the United States and México to investigate higher renewable energy integration on the interconnected North American electricity system. Through Natural Resources Canada, regional studies intended to identify the most promising electricity infrastructure projects to reduce GHG emissions are being undertaken with the four Atlantic Provinces and four western provinces.

The *Pan-Canadian Wind Integration Study* was released by the Canadian Wind Energy Association (CanWEA) in July [5]. It found no operational barriers to achieving 35% wind penetration in Canada by 2025. Other key findings include:

- Increased deployment of wind will yield significant emissions reductions of 32.3 million metric tons of CO_{2eq} in Canada.
- Increased wind penetration will lead to new revenue generation from electricity exports to the United States.
- Wind energy will have an avoided cost of 43.40 CAD/MWh (30.68 EUR/MWh; 32.29 USD/MWh) in the 20% penetration scenario and 40.50 CAD/MWh (28.63 EUR/MWh; 30.13 USD/MWh) in the 35% scenario, similar to the cost of recent North American projects.

The Waterloo Institute of Sustainable Energy studied the significant economic and environmental benefits of implementing solar and wind energy in Arctic communities. The study identifies several communities with the potential to save up to 10% of their energy costs over a ten-year span [8].

Natural Resources Canada (NRCan) continues to examine the impact of cold climate operation on Canadian wind farm performance. Current efforts involve quantifying cold climate-related energy, revenue, and GHG emissions losses. A summary report will be released in 2017.

The University of New Brunswick (UNB) is leading a four-year study on development and validation of advanced wind forecasting methods in partnership with TCE, the Wind Energy Institute of Canada (WEICan), and NRCan. The research will include evaluation and improvement of short-term wind forecasts from the Environment Canada wind speed forecast model, development and testing new ramp and icing forecasts, and testing and modeling bulk energy storage to alleviate residual forecast error.

5.4 Test facilities and demonstration projects

Tugliq Energy Co., who operates the energy supply systems to the Glencore-owned Raglan nickel mining complex in northern Quebec, has successfully demonstrated reliable wind-generated electricity for their remote site [9]. The 3-MW Enercon E-82 turbine, equipped with a cold climate package, has achieved 97.3% availability through harsh winter conditions since its installation in 2014. The turbine is coupled to an innovative storage system comprising a flywheel, a Li-ion battery, and a Proton Exchange Membrane (PEM) fuel cell fueled by hydrogen produced from excess wind energy.

Tugliq predicts fuel cost savings of over 40.0 million CAD (28.28 3 million EUR; 29.76 8 million USD) over 20 years. The 18.98 million CAD (12.42 million EUR; 14.12 million USD) project is supported by the Canadian government (12.62 million CAD; 8.92 million EUR; 9.39 million USD) and the Quebec government (6.5 million CAD; 4.6 million EUR; 4.8 million USD).

WEICan, located at North Cape, Prince Edward Island, is a non-profit, independent research and testing institute leading the development of wind energy across Canada. Its 10-MW wind R&D park was commissioned in April 2013 and features five DeWind D9.2 turbines and a 1-MW/2-MWh battery energy storage system.

Key accomplishments for the WEICan institute in 2016 include:

- **Energy storage and grid integration:** Recent demonstrations of operation in regulation, time shifting, stacked services, demand charge avoidance, and peak generator displacement have shown that the energy storage system can carry out the services effectively. They have also demonstrated the maintenance cycles, reduced efficiency, reduced availability, and charge rate limitations of battery storage systems [10].
- **Availability data:** Under a data benchmarking project, several wind farms across Canada are taking part in Generating Availability Data System (GADS) reporting, which allows comparison across the wind industry and with traditional electricity generators [11].

TCE, located in Gaspé, Quebec, is a center of expertise for wind energy R,D&D on wind farm performance optimization and renewable energy integration. Research results for 2016 include:

- Development and validation of an ice prediction model for wind farms.
- A three-year study of control optimization of wind turbines under icing conditions, in partnership with Senvion.
- A comparison of ice detection methods and sensors, including ice monitoring cameras at several sites in Canada and Europe.
- Testing and evaluation of an aviation lighting system for wind turbines and met masts to reduce light intensity and improve visibility.
- Development of inspection procedures for wind turbine blades using drones in partnership with industry.

5.5 Collaborative research

Canada currently participates in several IEA Wind TCP tasks:

- Task 19 Wind Energy in Cold Climates
- Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power
- Task 32 LIDAR: Wind Lidar Systems for Wind Energy Deployment

Canadian researchers also participate in the International Electrotechnical Commission (IEC) Technical Committee-88.

In 2017, Canada will be joining IEA Wind TCP Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN).

6.0 Next Term

In 2017, roughly 750 MW of new wind power capacity is expected to come online: 230 MW in British Columbia, 120 MW in Ontario, 400 MW in Quebec, and small projects in Nova Scotia totaling 5 MW.

Figure 3. Westbound train near Piikani Nation, Alberta, Canada (Photo credit: Jaq Murillo)

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Opening photo: Sunrise over Bear Mountain Wind Farm, Dawson Creek, British Columbia, Canada; 34 Enercon E-82 3 MW turbines (Photo source: © Enercon Canada Inc.)

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CWEA

1.0 Introduction

China continues to have the highest wind power capacity in the world. In China, 23,369 MW of new wind power capacity was installed in 2016, increasing the accumulated capacity to 168,731 MW. Grid-connected capacity increased to 149,000 MW with the addition of 19,300 MW installed in 2016. This accounted for 9% of installed power capacity nationwide.

The average full-load-hour of wind power was 1,742 hours in 2016, an increase of 14 hours from 2015. Wind-generated electricity totaled 241 TWh, representing an increase of 29.4%. Wind-generated electricity accounted for 4% of the total electricity generation, an increase of 0.7% over 2015. Wind power remains the third largest generation source in China, following thermal and hydro-electricity sources. The average wind curtailment rate was 17%, an increase of 2% compared to 2015.

In 2016, the Chinese government considered wind power development an important tool to promote the energy revolution, to adjust the energy structure, and to enhance national energy security. The government issued a series of policies and regulations to promote the healthy development of wind power, known as the 13th Five-Year Plan for Wind Power Development. In addition, Chinese companies made progress in R&D including developments for wind energy in cold climates and in low wind speed areas.

2.0 National Objectives

2.1 Targets

In 2016, the Chinese government released the 13th Five-Year Plan on Wind Power Development (2016-2020). This plan set several targets to promote the energy transition in China. First, new grid-connected wind power capacity will reach 79 GW during this five-year plan period. By the end of 2020, the installed wind power capacity will be 210 GW, and the installed offshore wind power capacity will total approximately 5 GW. Wind-generated electricity will reach 420 TWh, or 6% of the total electricity production.

Second, the 13th Five-Year Plan addresses the consumption of wind-generated electricity. By the end of 2020, the wind curtailment problem will be solved and the full-load hours in the northern regions of China will reach the minimum acquisition hours. Third, wind power equipment manufacturing and R&D capabilities will be improved. Three to five manufacturers are expected to reach an advanced international level with a significantly increased market share.

2.2 Policies supporting development

To promote the healthy development of the wind power industry, the Chinese government released the formal 13th Five-Year Plan in 2016. This will direct wind power market development and promote wind power integration and consumption.

The plan is a series of policies and regulations emphasizing centralized and distributed wind power development and optimizing the layout of wind power based on local consumption principles. It also stipulates that the eastern and southern regions with high consumption capacity should accelerate the construction of wind power.

The National Energy Administration (NEA) also announced a non-hydro renewable energy power generation quota evaluation system for thermal power plants (draft for comment). Per this quota, the electricity generated from non-hydro renewable energy in all thermal power plants will need to account for at least 15% of the thermal power generation in 2020.

3.0 Implementation and Deployment

3.1 Progress

By the end of 2016, China installed 23,369 MW of new wind power capacity (exclusive of Taiwan). This added capacity accounted for 43% of new global wind capacity for the year. The accumulated wind power capacity in China reached 168,731 MW, accounting for 34.7% of wind power capacity worldwide and maintaining the highest wind power installation in the world.

Compared to 2015, new wind installations decreased by 24%, though cumulative installation increased by 16% (Figure 1). In 2016, wind power generation reached 241 TWh, representing 4% of electricity generation.

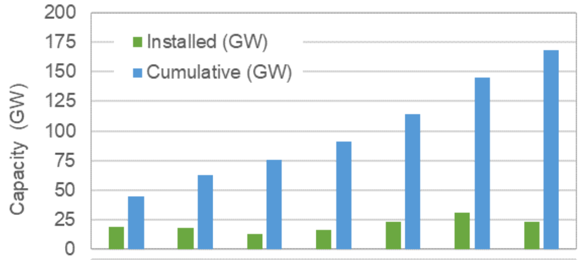
3.2 Operational details

A total of 11,953 new wind turbines were installed in 2016, bringing the national total of operating turbines to 104,934. The average capacity of newly installed wind turbines is 1.955 MW, an increase of 6.4% compared to 2015. The average capacity of all installed wind turbines increased to 1.608 MW in 2016.

The five provinces with the largest new installations were:

- Xinjiang (2.770 GW)
- Inner Mongolia (2.396 GW)
- Yunnan (1.955 GW)
- Hebei (1.675 GW)
- Shandong (1.625 GW)

Together, these accounted for 44.6% of the national new additions. The average full load-hours of operating wind farms was 1,742 hours, an increase of 14 hours compared to 2015.



	2010	2011	2012	2013	2014	2015	2016
🟩 Installed (GW)	18.9	17.6	13.0	16.1	23.2	30.8	23.4
🟦 Cumulative (GW)	44.7	62.4	75.3	91.4	114.6	145.4	168.7

Figure 1. New and accumulated installed capacity from 2010–2016 in China

The average development cost of a wind power project in 2016 was 8,157 CNY/kW (1,117 EUR/kW; 1,175 USD/kW), a decrease of 199 CNY (27 EUR; 29 USD) compared to 2015. The development cost of land-based wind energy was approximately 0.35 CNY/kWh (0.048 EUR/kWh, 0.050 USD/kWh).

Factors that influence this cost include levels of wind resources, construction conditions, mainstream wind turbines technologies, and wind farm operation levels. With current technology, and without considering the cost of long-distance transmission or the environmental and resource benefits of wind power, the cost of wind power is higher than that of coal-fired power by 0.12 CNY/kWh (0.016 EUR/kWh; 0.017 USD/kWh). If resources and environmental benefits are taken into consideration, the cost of wind power is nearly equal to that of coal-fired power generation.

3.3 Matters affecting growth and work to remove barriers

Integration and consumption are still significant problems limiting wind power development in China. Although wind-generated electricity increased by 29% in 2016, the average full-load-hour of wind power only increased by 14 hours.

Wind curtailment continues to be the main restriction on wind power development. The annual curtailed wind-generated electricity is 49.7 TWh. Gansu (43%), Xinjiang (38%), Jilin (30%), and Inner Mongolia (21%) are the four provinces with the highest wind curtailment rates in China. The government took several measures in 2016 to resolve this problem, implementing policies to increase peak regulation capacity and encourage inter-provincial compensation.

4.0 Impact of Wind Energy

4.1 Environmental impact

Based on predictions for wind-generated electricity in 2020, wind power will save 150 million tons of standard coal per year, and reduce 380 million tons of CO_2, 1.3 million tons of SO_2, and 1.1 million tons of NO_x. It will play an important role in reducing air pollution and controlling greenhouse gas emissions.

4.2 Economic benefits

Based on a sampling of domestic enterprises and considering the mean labor productivity in the manufacturing industry in China, is it estimated that every 1 MW of installed wind power capacity could produce about 15 jobs (13–14 jobs in manufacturing and about 1.5 jobs for installation and maintenance).

In China, wind related jobs increased from 502,400 in 2014 to 507,000 in 2015. More than 70% of the jobs are in manufacturing. The government estimates that more than 800,000 people will be employed in the wind power industry through 2020.

The accumulated wind power capacity in China reached 168,731 MW in 2016, accounting for 34.7% of wind power capacity worldwide.

4.3 Industry development

In 2016, more than 100 developers had new installations in China. The accumulated installed capacity of the top ten developers accounted for 69.4% of the total installation (Table 2). The top five developers in China accounted for 38.1% of new wind installations and the top ten developers accounted for 58.8% of new wind capacity.

Twenty-five manufacturers in China have new wind energy installations. The top manufacturer of new installation was Goldwind (6,343 MW), accounting for 27.1% of new wind installations, which greatly benefited the wind power industry. The top ten manufacturers accounted for 84.2% of the new wind installations in 2016 (Table 3).

In the past four years, the market share has gradually concentrated in large companies. The top five manufacturers' market share increased from 54.1% in 2013 to 60.1% in 2016, and the top ten manufacturers' market share increased from 77.8% in 2013 to 84.2% in 2016.

5.0 R,D&D Activities

5.1 National R,D&D priorities

The Ministry of Science and Technology of the People's Republic of China has been supporting the new Science and Technology Support Research Program since July 2014, and will continue to do so until July 2017. Two projects are related to wind power:

Intelligent controls, monitoring and operations: This includes research and demonstration projects on the intelligent control of wind turbine and key technologies of smart wind farms (12.79 million CNY; 1.75 million EUR; 1.84 million USD), intelligent monitoring and maintenance dispatching system for large scale wind farms (7.72 million CNY; 1.06 million EUR; 1.11 million USD), key technologies of intelligent operation and maintenance of large-scale wind farms (6.09 million CNY; 0.83 million EUR; 0.88 million USD), and key technology of intelligent wind farm design optimization (10.7 million CNY; 1.5 million EUR; 1.5 million USD).

Table 1. Key National Statistics 2016: China

Total (net) installed wind power capacity	168,731 MW
Total offshore capacity	1,630 MW
New wind power capacity installed	23,370 MW
Decommissioned capacity	---
Total electrical energy output from wind	241 TWh/yr
Wind-generated electricity as percent of national electricity demand	4%
Average national capacity factor	18.5%
Target	210 GW by 2020
National wind energy R&D budget	RE: 10 million CNY (1.37 million EUR; 1.44 million USD)

Table 2. Top 10 Developers of New Wind Installations in China during 2016 (Source: CWEA)

Rank	Developer	Capacity (MW)	Share
1	Guodian Group	2,610	11.2%
2	Datang Group	1,830	7.8%
3	SPIC	1,780	7.6%
4	Huaneng Group	1,430	6.1%
5	CGN	1,260	5.4%
6	Guohua	1,230	5.2%
7	Huadian Group	1,040	4.5%
8	China Suntien Green Energy	980	4.2%
9	Tianrun	810	3.5%
10	Huarun	790	3.4%
	Others	9,620	41.2%
	Total	**23,369**	**100.00%**

Table 3. Top 10 Manufacturers for New Wind Installations in China During 2016 (Source: CWEA)

Rank	Manufacturer	Capacity (MW)	Share
1	Goldwind	6,343	27.1%
2	Envision	2,003	8.6%
3	Mingyang	1,959	8.4%
4	United Power	1,908	8.2%
5	CSIC Haizhuang	1,827	7.8%
6	Shanghai Electric	1,727	7.4%
7	XEMC-Wind	1,236	5.3%
8	Dongfang Turbine	1,227	5.2%
9	Windey	724	3.1%
10	Sany	715	3.1%
	Others	3,703	15.8 %
	Total	**23,369**	**100.00%**

The expected results of this project are as follows:

- Developing an intelligent wind turbine control system with self-learning ability that can automatically adapt to differences in operating environment, wind resource, and individual unit performance.
- Demonstrating a monitoring and maintenance system in a 50-MW wind farm with at least a 90-day test period. Operational hours must increase 5% compared to the standard and the fault prediction accuracy should reach 90%.
- Establishing a wake model suitable for Chinese wind resources and constructing a 50-MW demonstration wind farm to generate at least 10% more electricity than normal wind farms.

Turbine testing technologies: This includes research focusing on key offshore wind turbine test technology and equipment (27.72 million CNY; 3.80 million EUR; 3.99 million USD), as well as large-scale wind turbine drive chain test technology (10.96 million CNY; 1.50 million EUR; 1.58 million USD).

The expected results of this project are as follows:

- Building a 7-MW offshore wind turbine test capability.
- Developing technical specifications for the large-scale wind turbine drive chain test.

5.2 R&D budget

In 2017, the Ministry of Science and Technology of the People's Republic of China launched the National Quality Infrastructure Project. The total budget for renewable energy is 10 million CNY (1.37 million EUR; 1.44 million USD). Two projects are related to wind power, as follows:

1. Research on the testing, monitoring, and evaluation technology of key renewable energy equipment in service, focusing on detective techniques without disassembly for key mechanical parts of wind turbines; early damage and operation condition monitoring technologies; and key technology of energy storage battery.
2. Research on key technologies of quality evaluation of renewable energy and related products focusing on reliability design and evaluation technology for wind turbines; quality evaluation technology for the whole production process of key components of wind turbines; and evaluation technology of performance, operational reliability, and residual life of wind turbines.

5.3 Research results

With the progress of wind turbine technology and the development of wind power in low wind speed areas, the reliability of megawatt wind turbines that can adapt to low wind speed areas has drawn the attention of many manufacturers.

Windey tested the reliability of megawatt wind turbines from capacity and terrain aspects. The reliability of low-speed wind turbines was assessed from two indicators: Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR). MTBF reflects the failure rate of wind turbines, while the MTTR reflects the failure complexity, response time, and the failure dealing ability.

The results indicate that the operation reliability of 1.5-MW and 2.0-MW turbines are better and more mature. The performance of the same low-speed wind turbines in different terrain is slightly different. In general, low-speed units in inland mountain areas show higher reliability compared to those in the coastal hills.

5.4 Test facilities and demonstration projects

Concrete turbine towers are playing an increasingly important role as wind power capacity installation increases. In 2016, Goldwind conducted research on concrete tower development. Various types of concrete towers were designed and tested. They completed the engineering acceptance, technical improvement, and semi-annual testing of the first 2.5-MW cast-in-place concrete tower prototype. Additionally, the design, mould manufacture, and hanger production of the 93/1500-HH100m precast concrete tower were finished. Finally, Goldwind completed the main pre-stress design and confirmed the system for the conversion section and for lifting the 121/2500-120m prefabricated concrete tower.

5.5 Collaborative research

By the end of 2016, the Chinese Wind Energy Association (CWEA) had arranged for 28 domestic wind power companies, research institutes, and universities to attend IEA Wind TCP 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 27: Small Wind Turbines in High Turbulence Sites
- 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;
- Task 35: Full-Size Ground Testing for Wind Turbines and Their Components
- Task 36: Forecasting for Wind Energy.

Results relevant to wind power in China are as include a study of wind energy in cold climates and water drop deformation and water drop breakup research (Figure 2), numerical simulation of flow fields in buildings with a triangular roof under three wind direction (Figure 3), wind lidar systems test, and reliability data and optimization of wind turbines.

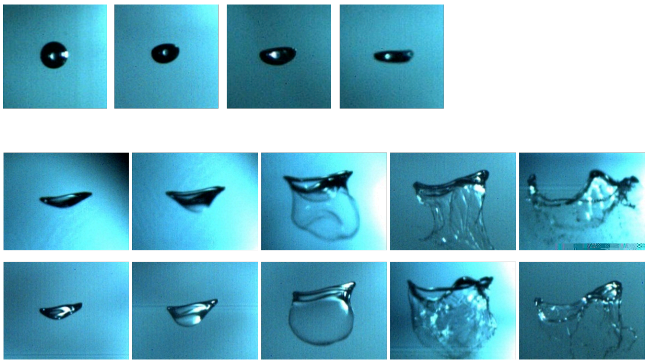


Figure 2. Water drop deformation and breakup in the study of cold climates (Source: China Aerodynamic Research and Development Center)

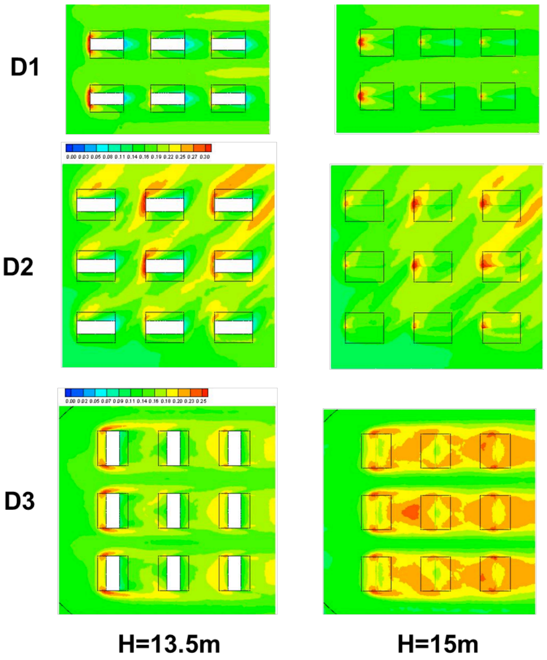


Figure 3. Numerical simulation of flow fields in buildings with triangular roofs under three directions (Source: Inner Mongolia University of Technology)

6.0 Next Term

Wind power will continue to develop in 2017, likely at the lower rate as 2016. Industry will focus on changing the development model, improving product quality, and advancing innovation. CWEA will continue to do its best to organize all related works.

References:

Opening photo: Wind farm in China (Photo credit: Huang Bin)

Authors: He Dexin, Du Guangping, and Wei Jia, Chinese Wind Energy Association (CWEA), China.

Denmark

1.0 Introduction

Wind power capacity in Denmark increased by 169 MW in 2016, bringing the total to 5,246 MW (Table 1). In 2016, 228 MW of new turbines were installed while 59 MW were dismantled. No new wind turbines were installed offshore in 2016. Electricity production from wind turbines corresponded to 37.6% of the domestic electricity supply, compared to 42% in 2015. In 2016, Denmark's energy consumption came from the following sources:

- **38.4% from oil**
- **28.9% from renewable sources**
- **16.2% from natural gas**
- **11.7% from coal**
- **2.4% from imported electricity**
- **2.2% from nonrenewable waste**

The wind energy index fell from a record 114 in 2015 to 90.2 in 2016. This resulted in a decline for both the wind energy production and the wind share of domestic electricity supply, despite increased capacity.

The largest rated turbine is still the 8-MW Vestas with a 140-m tower, which was erected at the Østerild test site during December 2013 and January 2014. Two other 8-MW Vestas demo turbines on 118-m towers were installed near the harbor of Esbjerg in 2015 and 2016. Publicly-funded wind R&D was reduced substantially in 2016.

2.0 National Objectives

In 2016, the Danish government set a new objective of 50% renewable energy by 2030. The government also announced that it will present a proposal for a new energy agreement before the end of 2017. This will replace the March 2012 energy agreement (see *Accelerating Green Energy Towards 2020, Energy Policy in Denmark*, and past IEA Wind TCP Annual Reports [1, 2]). The latest update on the 2012 agreement was the Minister's report to Parliament on 29 April 2016 (in Danish) [3].

The Danish Parliament decided in November 2016 to transfer the funding of Danish support for renewables to the state budget over a five-year period and to accept the bids for three offshore wind farms totaling 950 MW.

2.1 Targets

Denmark has targets for 30% renewable energy in total energy consumption by 2020 and 50% by 2030. Further plans include phasing out fossil fuels to make Denmark independent of fossil fuels by 2050. Wind power targets include adding:

- 1,000 MW of large-scale offshore wind farms before 2022. Through a tendering process, this goal will be reached with the Horns Rev III 400 MW wind farm in operation in 2017–2020, and the Krieger Flak 600 MW wind farm in operation before 2022. The European Union (EU) will support the grid connection with 1.1 billion DDK (1.5 million EUR; 1.6 million USD).
- 350 MW in near-coast offshore installations using a tendering process and 50 MW of offshore turbines for R&D (reduced to 28 MW per the new Public Service Obligation (PSO) agreement)
- 500–600 MW net land-based capacity before 2020. This will be comprised of 1,800 MW land-based capacity of which 1,300 MW is repowering.

2.2 Policies supporting development

Green development, and thus the support mechanism for wind turbines, have been financed through the PSO. Because of low electricity market prices, the PSO cost rose substantially. Additionally, the EU discovered a conflict with the EU Treaty. Therefore, in November 2016, Parliament agreed to abolish the PSO and gradually transfer the cost to the governmental budgets.

3.0 Implementation and Deployment

3.1 Progress

Figure 1 shows the wind power capacity and electricity production of wind turbines in Denmark since 1980. The net added wind capacity in 2016 was 169 MW, bringing the total to 5,246 MW (Table 1).

In 2016, 228 MW (545 new turbines) were installed, all on land, while 59 MW (185 turbines) were dismantled (Figure 2). Of the new turbines, 467 are smaller than 25 kW. A detailed history of installed capacity and production in Denmark can be downloaded from the

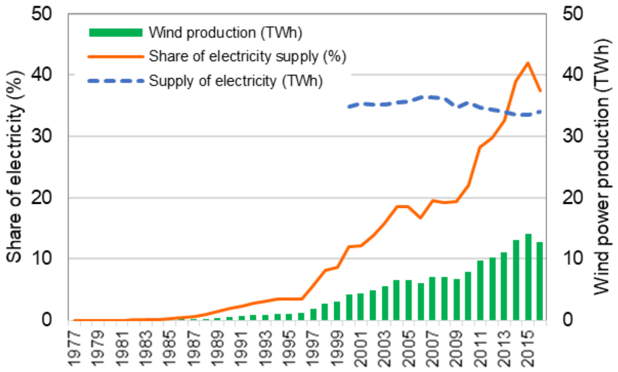


Figure 1. Danish wind power production and share of electricity, 1980-2016

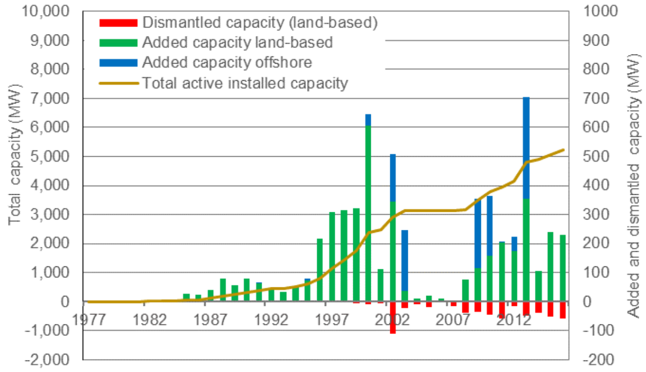


Figure 2. Added, dismantled, and total capacity per year in Denmark, 1980-2016

Danish Energy Agency website [4]. The largest rated turbine installed in 2016 was a MHI Vestas 8-MW in Maade, Esbjerg.

3.2 Operational details

At the end of 2016, 6,129 turbines with a capacity of 5,245 MW were in operation and the total production for the year was 12.8 TWh. The average capacity factor was 28.4% for turbines operating the whole year (average wind index 90.2%). The 1,271 MW of offshore wind farms alone counted for nearly 37% of the production (4.65 TWh) with an average capacity factor of 41.8%.

The average capacity of installed turbines was 419 kW in 2016 due to installation of many small household turbines. The average capacity of the 75 new turbines above 25 kW was 2.9 MW (Figure 3). The largest running project is Anholt (400 MW). Maps of existing offshore winds farm can be found in previous IEA Wind TCP Annual Reports.

3.3 Matters affecting growth and work to remove barriers

Municipalities oversee the planning process of land-based wind turbines and the Danish Energy Agency oversees offshore wind turbines. Updated information regarding the planning process, regulation, and legislation related to wind turbines can be found at Vindinfo.dk [5].

In December 2016, the 600-MW Kriegers Flak Concessions Agreement was signed by the government. Licenses for pre-investigations and establishment were awarded to Vattenfall A/S, who had offered the lowest price at 0.372 DKK/kWh (0.050 EUR/kWh; 0.053 USD/kWh) to be paid for 30 TWh. This historically low electricity price covers the electricity consumption of more than 600,000 households and powerfully contributes to the Danish target of fossil independence by 2050.

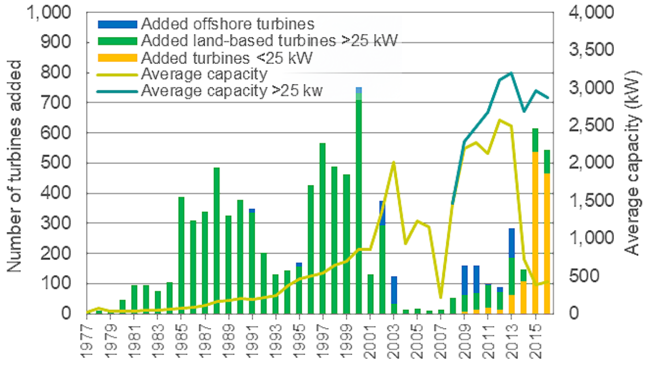


Figure 3. Average capacity and number of new turbines added per year

In 2016, Danish offshore wind farms (1,271 MW) accounted for nearly 37% of the country's wind-generated electricity production (4.65 TWh) with an average capacity factor of 41.8%.

Also in December, two agreements for near-shore wind farms in the North Sea were also signed with Vattenfall A/S, offering a price of 0.475 DKK/kWh (0.064 EUR/kWh; 0.067 USD/kWh). These farms are the 170-MW Vesterhav Nord Offshore Wind Farm and the 180-MW Vesterhav Syd Offshore Wind Farm. The signature came after some political discussion of the financing of these parks in relation to the current PSO negotiations as mentioned in Section 2.2. More information on the status and progress of offshore windfarms can be found on the DEA English website [6].

4.0 Impact of Wind Energy

4.1 Environmental impact

The environmental benefits from wind energy production in 2016 have been calculated assuming coal was being substituted. The results include:

- saved coal=4.2 million tons (332 g/kWh);
- reduced CO_2=9.9 million tons (772 g/kWh);
- reduced SO_2=893 tons (0.07 g/kWh);
- reduced NO_x=2.3 thousand tons (0.18 g/kWh);
- reduced particles=255 tons (0.02 g/kWh); and
- reduced cinder/ash=667 thousand tons (52.3 g/kWh) [7].

4.2 Economic benefits

Aside from the environmental benefits, the economic benefits of wind power to society are mainly from exports of technology. Generally, the electricity price in Denmark is controlled through the North Pool market and thereby by the German power prices from coal production (marginal rates), and on shorter terms by Scandinavian hydropower. In periods with low consumption, high wind power production can lower electricity prices, resulting in lower sales prices for electricity from wind turbines.

Table 1. Key National Statistics 2016: Denmark

Total (net) installed wind power capacity	5,246 MW
Total offshore capacity	1,271 MW
New wind power capacity installed	228 MW
Decommissioned capacity	59 MW
Total electrical energy output from wind	12.8 TWh
Wind-generated electricity as percent of national electricity demand	37.6%
Average national capacity factor	28.4%
Target	50% by 2020
National wind energy R&D budget	N/A

4.3 Industry development

Denmark is home to some of the world's largest wind turbine manufacturers, including Vestas Wind Systems and Siemens Wind Power. Furthermore, DONG Energy and Vattenfall have driven the development of offshore wind technologies through the establishment and operation of offshore wind farms. Other large, leading enterprises within wind include A2SEA (offshore wind turbine installation), Bladt Industries (offshore wind turbine foundations), and LM Wind Power (turbine blades). However, in addition to the large, well-known players, Denmark also boasts many smaller and very successful niche companies in the wind power industry.

As reported last year, 2015 was the best year in the Danish wind industry since the global financial crisis in 2008–2009 and both turnover and number of full-time employees increased [8]. In 2015, 31,251 people were employed in the Danish wind industry, an increase of 3.8% since 2014.

Turnover increased from 11.5 billion EUR (12.2 billion USD) in 2014 to 11.9 billion EUR (12.5 billion USD) in 2015. Wind exports decreased from 7.3 billion EUR (7.7 billion USD) in 2014 to 6.5 billion EUR (6.8 billion USD) in 2015. However, since 2013 the exports have increased 6%. Data for 2016 have not yet been released. Compared to 2006, exports have increased 22.6% and in 2014, exports hit the highest level since 2008–2009.

5.0 R,D&D Activities

An annual report on the energy research program's budget, strategy, and projects was published by the Danish Energy Association in cooperation with Energinet.dk, the Energy Technology Development and Demonstration Program (EUDP), and the Innovation Fund Denmark [9]. The 2016 report is available online in Danish with updated lists of Danish-funded energy technology research projects at www.energiforskning.dk [10]. Funded projects are in a broad range from fundamental research to large-scale demonstration projects, and ready-to-market projects.

5.1 National R,D&D priorities

Danish capabilities in wind energy are based on a network of large and small enterprises and a range of research and development centers. DTU Wind Energy (Technical University of Denmark) has played a key role in this development and is to day recognized as one of the world's leading wind energy knowledge centers [11].

In 2016, EUDP developed a new strategy for 2017–2019 [12]. The strategy takes a broader and more global perspective than previous strategies in order to identify the best areas to invest in the future. Priorities and allocating funds are based on an analysis of the following three topics:

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

In 2016, the Megawind project also released a strategy for extending the useful lifetime of a wind turbine, a report on technological solutions to reduce the environmental impacts of wind-energy systems, and a report with recommendations for test and demonstration facilities for wind energy needed to promote a competitive wind industry in Denmark [13–15].

5.2 R&D budget

In 2016, EUDP granted 210 million DKK (28 million EUR; 30 million USD) to 50 new energy research development projects out of a total of 465 million DDK (62 million EUR; 66 million USD) requested. Wind energy projects received grants totaling of nearly 100 million DDK (13 million EUR; 14 million USD).

5.3 Research results

One of the most interesting research results of the year is the new developments of wind scanners. The scanners can provide detailed knowledge of the wind's interaction with the turbine rotor. This can be used to evaluate and improve the computer models used to simulate load and control, generally optimizing the turbines [16].

A consortium of researchers from all the Nordic countries completed a voltage-sourced converter (VSC) project aiming to develop offshore wind power at a large scale over the past five years. The results include new optimized solutions to improve the technical performance of VSC-based high-voltage, direct current (HVDC) grids, development of control and operation systems for clusters of wind power plants, and a grid design for the Baltic Sea [17].

5.4 Test facilities and demonstration projects

Denmark owns several unique test facilities such as the Lindø Offshore Renewables Center (LORC), the Test Center for Large Wind Turbines at Høvsøre, the Østerild National Test Centre for Large Wind Turbines, and the Powerlab DTU. Detailed information on the activities and test sites at DTU and LORC can be found at their websites [18, 19].

DTU Wind Energy is operating three wind turbine test sites in Denmark. These test sites are situated at the DTU Risø Campus in Roskilde, the Høvsøre Test Site for Large Wind Turbines at Lemvig, and the Test Center Østerild at Thisted. There are plans to expand the Høvsøre and Østerild sites with two more test facilities each, both allowing for taller turbines (Høvsøre: seven sites up to 200 m, and Østerild: nine sites up to 330 m).

In May 2012, the Ministry of Science, Innovation and Higher Education decided to establish a wind tunnel at DTU Risø Campus as a part of the national research infrastructure. The wind tunnel is financed by the government, DTU, and Region Zealand. The project will be organized by scientists from DTU Wind Energy in cooperation with DTU Campus Service and the engineering consultancy company Alectia during 2016 and 2017. A symbolic groundbreaking ceremony was held June at the DTU Risø Campus to mark the beginning of construction and the wind tunnel is expected to be finished by May 2017.

Another new large-scale facility is under construction at DTU as part of the Villum Center for Advanced Structural and Material Testing (CASMaT). The construction began in autumn 2016 and the test facility will be operational by summer 2017.

5.5 Collaborative research

Denmark takes part in several international cooperative energy technology R,D&D projects. Public support is offered to promote Danish companies, universities, and research institutions to participate in IEA Technology Collaboration Programmes (TCPs), EU programs, and in the Nordic Energy Research programs.

6.0 Next Term

The next four offshore wind farms in Denmark will be built by Vattenfall. The Horns Rev III will be constructed during 2017–2019 with MHI Vestas V164-8.0 MW turbines. The Krieger's Flak project is planned for construction during 2018–2021, but the decision on turbine type has not yet been made. The two planned near-shore wind farms, Vesterhav North and South, will be in operation before the end of 2020. For more information see the project websites [20–22].

The 28-MW pilot offshore project with four Siemens 7-MW turbines in Nissum Broads is expected to be in operation by the end of 2017.

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Opening photo: MHI Vestas 8 MW at Maade (Photo credit: MHI Vestas Offshore Wind)

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European Union/WindEurope

1.0 Introduction

In 2016, the European Union (EU) connected 12.5 GW of new wind energy capacity—a decrease of 3% compared to 2015 (Figure 1). Of the new capacity, land-based installations accounted for 10.9 GW and 1.57 GW offshore. The total cumulative wind capacity was 154 GW at the end of 2016, a growth of 8%. Wind power generated almost 300 TWh in 2016, covering 10.4% of the EU's electricity demand [1, 2].

The total European Commission (EC) funding specifically dedicated to wind energy technology increased to 65 million EUR (68 million USD) in 2016. Offshore technology receives the highest share of funding, followed by new turbine materials and components, while funding for grid integration and resource assessment is decreasing.

2.0 National Objectives

The Renewable Energy Directive is the main policy driver for wind energy in the EU. This directive established the overall legal framework for the production and promotion of energy from renewable sources in the EU [3]. It requires the EU to fulfil at least 20% of its total energy needs with renewables by 2020.

This binding target must be achieved through individual national targets and technology-specific targets. In its proposal for a revised Renewable Energy Directive, the EC proposes a target of at least 27% renewables in the final energy consumption by 2030 [4].

2.1 Targets

The EU target is a 20% share of renewable energy in final energy consumption by 2020. All EU countries have adopted national renewable energy action plans (NREAPs), which include specific targets for wind energy.

Within the 28 EU member states, ten are already above their general 2020 RES targets. According to the EC energy model PRIMES, 12 other countries are on track to reach their targets, but need to continue their current efforts to reach their RES targets by 2020. The remaining six EU Member States—Hungary, Ireland, Luxembourg, the Netherlands, and Slovenia—are not on track for their 2020 RES target and must increase their action to meet their targets.

By the end of 2016, the total installed wind power capacity in the EU was 153.7 GW, 72% of the 2020 target. When looking at the NREAP expectations for wind energy for 2016, the EU met 99% of the 2016 target.

2.2 Policies supporting development

Current state aid guidelines for environmental protection and energy encourage EU member states to shift their wind energy regulatory framework toward schemes that will ensure higher market compatibility [5].

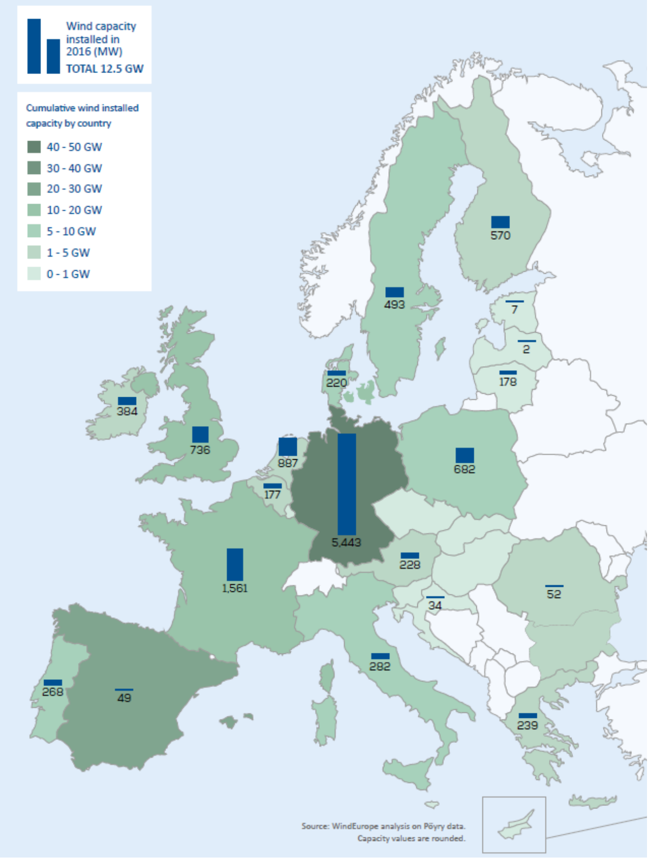
In 2016, the most common support schemes for land-based wind were feed-in tariffs (FITs), followed by feed-in premiums. In offshore wind energy, new projects were supported by feed-in premiums, followed by tradable green certificates. Subsidies like feed-in tariffs grant a high level of security to investors but neglect market signals which is the basis for higher shares of wind energy in the energy system. EU member states are increasingly introducing competitive tender-based support schemes. These schemes are currently being applied in nine EU member states for land-based wind and seven member states for offshore wind.

Some EU member states have planned regulatory changes to become effective in 2017; Germany and Hungary are implementing a feed-in premium tender-based support scheme, and new market-based frameworks are under development in Finland, Ireland, Lithuania, and Slovakia.

3.0 Implementation and Deployment

3.1 Progress

During 2016, 12.5 GW of new wind power capacity was installed and grid-connected in the EU, 3% less than 2015 (Figure 1). Land-based



Source: WindEurope analysis on Pöyry data.
Capacity values are rounded.

Figure 1. Gross and cumulative installed capacity in the EU in 2016

By the end of 2016, the total installed wind power capacity in the EU was 153.7 GW, 72% of the 2020 target.

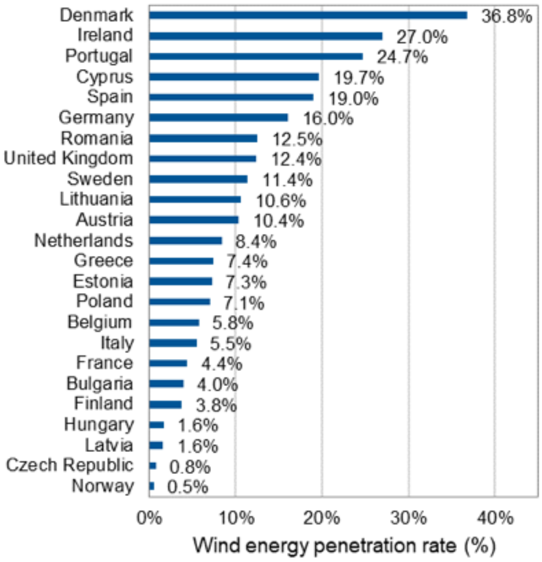


Figure 2. Wind penetration rates in Europe

installations accounted for 10,923 MW, and 1,567 MW were installed offshore. Cumulatively, 153.7 GW are now installed in the EU, a growth of 8% in 2016. The EU member states with the largest installed capacity are Germany, Spain, the United Kingdom, France, and Italy. By the end of 2016, Austria, Croatia, Denmark, Germany, and Sweden had reached their proposed 2020 targets for wind energy.

In 2016, wind energy generated enough electricity to meet 10.4% of the EU-28 total electricity demand. Denmark was the EU member state with the highest penetration rate (37%), followed by Ireland (27%), and Portugal (25%). Eleven out of the 28 member states had a wind penetration rate of more than 10% (Figure 2).

3.2 Operational details

In 2016, EU land-based wind capacity factors averaged at 21.7%, which is a decrease compared to 2015.

The size and type of wind turbines installed in the EU in 2016 varied between member states. For example, the wind turbines in Sweden and Finland had an average power rating of more than 3.1 MW, while the turbines installed the UK and Spain had an average rating of less than 2 MW. Regulatory restrictions on tip height, project duration, and wind regimes (low-speed or high-speed) can account for the variation in wind turbine ratings in the different member states.

Offshore, load factors range between 33.1% and 42.9% in the five biggest EU markets (Figure 3). The highest monthly load factor was in the UK in December 2016, with a load factor of 68.2%.

3.3 Matters affecting growth and work to remove barriers

Instability in legislation and retroactive changes are the main barriers for wind energy deployment. The lack of visibility in the post-2020 period for even deployment across Europe is particularly challenging.

Only seven out 28 member states have commitments and policies in place beyond 2020. The EC's proposed Clean Energy Package addresses these issues, however, until the package is adopted by the European Council and the European Parliament, the regulatory framework post-2020 remains uncertain. The EU wind energy sector also suffers from long permitting and siting procedures in some countries due to potentially adverse interaction with civil and military aviation, environmental constraints (land-based and offshore), and burdensome administrative procedures.

4.0 Impact of Wind Energy

Wind energy represents a great benefit for the European economy and to the environment. The wind energy sector employs 330,000 people in Europe and represents an annual turnover of more than 70 billion EUR (74 billion USD). New installed wind power capacity replaces polluting assets, reducing CO_2 emissions by more than 200 million tons in 2016 (according to Joint Research Centre's calculator).

4.1 Environmental impact

Wind energy plays an increasingly important role in the EU energy system as member states adopt more ambitious climate and energy targets, moving toward a decarbonization of the EU economy. Wind energy brings considerable environmental benefits in terms of greenhouse gas (GHG) emission reductions—a key technology in fighting climate change.

Future GHG emissions potentially avoided by wind energy in the EU 28 can be estimated based on the future scenario of electricity generation mix [6] and considering three different approaches in which wind energy may replace:

1) only natural gas

2) a mix of high-carbon technologies with a constant emission factor of 560 g CO_2/kWh [7]

3) the future mix of high-carbon technologies estimated each year.

Annual avoided CO_2 emissions in the EU would reach between 400-550 million tons (Mt), depending on the assumptions used (Figure 4). Cumulative avoided CO_2 emissions range between 8,700 Mt and about 13,000 Mt for the period 2015-2050. This is approximately 2.5 to 3.5 times the current annual CO_2 emissions from the energy sector in the EU.

4.2 Economic benefits

Europe invested a total of 27.5 billion EUR (29.0 billion USD) in wind energy in 2016, a 5% increase from 2015. This is largely due to investments in offshore wind, which increased 39% compared to

Table 1. Key Statistics 2016: European Union	
Total (net) installed wind power capacity	153.7 GW
Total offshore capacity	12.6 GW
New wind power capacity installed	12.5 GW
Decommissioned capacity	0.5 GW
Total electrical energy output from wind	296 TWh
Wind-generated electricity as percent of European electricity demand	10.4%
Average European capacity factor	Land-based 22.0%
Target	Total energy: 20% RES by 2020

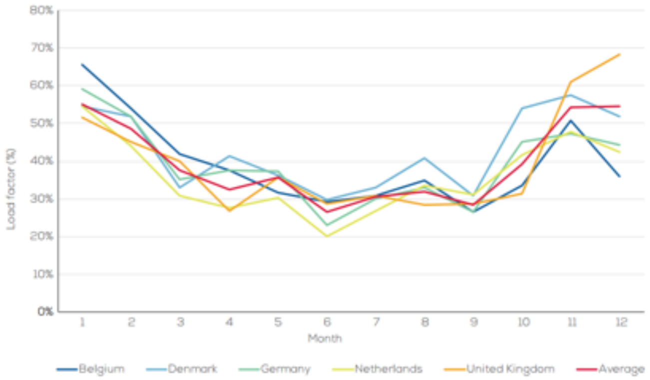


Figure 3. Capacity factors of offshore wind in 2016 in the different EU countries (Source: WindEurope)

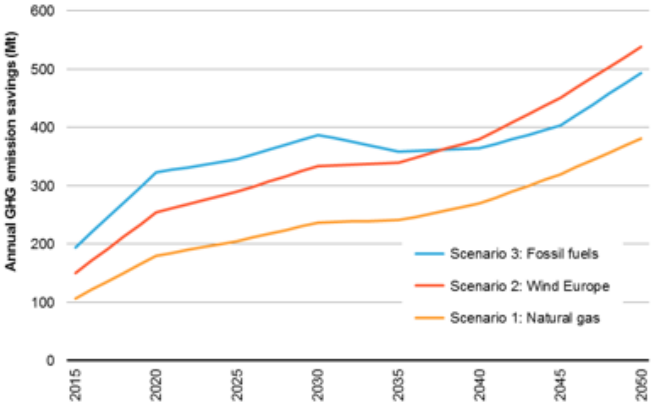


Figure 4. Avoided CO_2 emissions in the EU 28 between 2015 and 2050 (Source: JRC)

2015. There were 10.3 GW of new wind capacity financed in 2016. The United Kingdom was the biggest investor in wind energy for the second consecutive year accounting for 46% of the total wind energy investments made in 2016 (12.7 billion EUR; 13.4 billion USD). Wind energy investments accounted for 86% of new clean energy finance in 2016, compared to 67% in 2015. Offshore wind projects were responsible for more than half of the investment activity in the renewable energy sector.

4.3 Industry development

In 2016, more than 50% of turbines were sold directly to power producers or utilities. Remaining turbines were sold to developers or private investors. As the wind technology is maturing, European manufacturers are now facing a consolidation phase, with two important mergers occurring in 2016.

Table 2. Wind Energy-Specific Funding Under H2020 for Projects Starting in 2016

H2020-Funded Projects	Total Project Cost (million EUR; million USD)	EC Contribution (million EUR; million USD)	Number of Projects
Wind-specific projects	81.99; 86.33	49.20; 51.81	18
Non-wind specific projects[a]	19.57; 20.611	15.76; 16.60	6
Total funding for wind energy	101.57; 106.95	64.96; 68.40	24

[a] Non-wind specific projects include projects dealing with grid integration of renewables, projects developing materials for extreme conditions (cold climates, offshore applications), or projects developing common platforms/components (e.g. with wave/tidal energy)

European wind turbine manufacturers continue exporting wind turbines outside of the EU. A total of 77 GW were exported by European turbine manufacturers since the emergence of wind energy.

5.0 R,D&D Activities

Horizon 2020 is the main funding instrument for energy research and development at the EU level, with a budget of about 6.0 billion EUR (6.3 billion USD). In 2016, 24 projects started with total funding of about 65 million EUR (68 million USD) (Table 2).

5.1 R,D&D priorities

The research, development, and innovation priorities of the EU embrace the spectrum of elements necessary to reduce the cost of wind energy:

- 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

5.2 R&D budget

Total EC funding dedicated to wind energy technology increased to 65 million EUR (68 million USD) in 2016. Average EC funding per project for wind has remained relatively stable since 2009, with around 1.7-3.0 million EUR (1.8-3.2 million USD) per project.

Figure 5 shows how research and innovation (R&I) priorities translated into actual projects since 2009 under H2020 and its predecessor FP7. The item "other" in Figure 5 includes exploratory R&D such as kites or other R&I grants such as support for technology platforms or PhD programs.

5.3 Research results

EC-funded projects were completed in 2016, such as MAREWINT, which focused on new materials and reliability in offshore wind turbines technology, CLUSTERDESIGN, which developed a toolbox for offshore wind farm cluster design, and WINDTRUST, which demonstrated more reliable innovative designs on a 2-MW wind turbine. More specific information on EU projects can be found in the CORDIS projects and results database [9].

5.4 Test facilities and demonstration projects

Of the 24 projects under the H2020 program, 16 are funded under the Small and Medium-sized Enterprises (SME) instrument with an EC contribution of 50,000 EUR (52,650 USD) in most cases.

The key EU-funded projects (non-SME) focus on three main areas: maintenance and condition monitoring systems, new turbine materials and components, and offshore technology.

- **CL-Windcon** aims to reduce the levelized cost of energy (LCOE) by 10% by optimizing wind farm design and operation to increase energy production and reduce O&M and material costs. The project will treat a wind farm as a real-time optimization problem, addressing advanced modelling and open-and-closed loop control algorithms at a farm level.

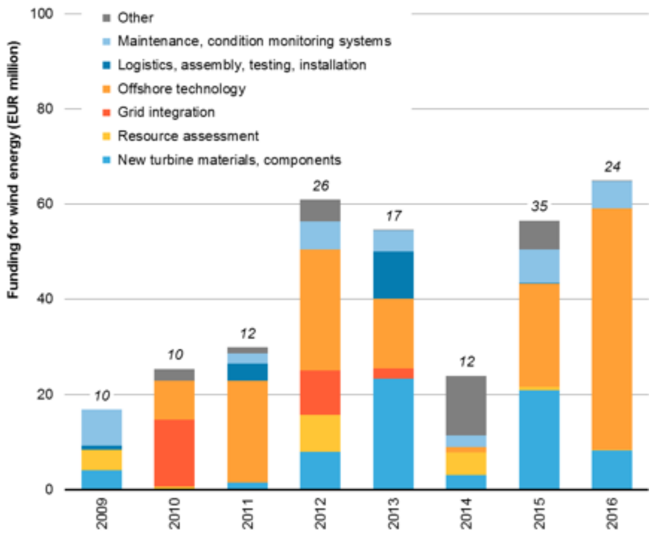


Figure 5. Evolution of EC R&I funding under FP7 and H2020 for wind and number of projects between 2009 and 2016

- **POWDERBLADE** is developing an innovative technology involving carbon/glass fibers in powder epoxy to produce wind turbine blades larger than 60 m. This will reduce wind turbine costs by 20%, encourage rapid market deployment of large turbines, and increase productivity of low-carbon energy.
- **EIROS** will develop self-healing, erosion resistant, and anti-icing materials for fiber-reinforced composite aerofoils and structures by introducing novel additives to the bulk resin. These materials can be adapted for wind turbine blades and aerospace wing leading edges, cryogenic tanks, and automotive fascia.
- **LORCENIS** aims to extend the life of energy infrastructure, even under extreme operating conditions, with long-reinforced concrete, using a combination of novel technologies and customized methodologies for cost-efficient operation.
- **PROMOTION** will develop and demonstrate three key high-voltage direct current (HVDC) technologies, a regulatory and financial framework, and an offshore grid deployment plan for 2020 and beyond [10].
- **DEMOGRAVI3** is the largest funded project, with a total cost of about 26.5 million EUR (27.9 million USD) and an EC contribution of 19 million EUR (20 million USD). Using an innovative hybrid steel-concrete offshore sub-structure for transitional water depths between 35–60 m (GRAVI3), it will produce a full-scale demonstration foundation, equipped with a grid-connected 2-MW offshore wind turbine. It will sustainably reduce the levelized cost of energy by up to 15%.
- **ELICAN** will develop a deep-water prototype substructure consisting of an integrated self-installing precast concrete telescopic tower and foundation supporting 5-MW offshore wind turbines. This will allow for crane-free offshore installation of the complete substructure and turbine, thus avoiding dependence on heavy-lift vessels, resulting in an expected cost reduction of more than 35%.
- **DemoWind 2** aims to support the development and demonstration of technologies which can reduce the cost of offshore wind energy [11]. This project is cofounded by Offshore Wind European Research Area Network (ERA-NET) and the EU's Horizon 2020 program, brings together European R&D funding organizations from six countries: Belgium, Denmark, the Netherlands, Portugal, Spain, and the UK.

5.5 Collaborative research

Generally, projects funded by the EC foster international cooperation and most require international collaboration between industry and research organizations. The Joint Research Centre of the EC has been and will continue to participate in IEA Wind TCP Task 26 Cost of Wind Energy.

6.0 Next Term

The next two years, 2017 and 2018, should be transition years for the wind energy sector. Support schemes are changing dramatically. Land-based wind should follow its current 12 GW/year level during these two years, but might decrease from 2019 onwards. There is a strong pipeline of offshore projects, ensuring over 3 GW of new capacity will be installed 2017, reaching at least 24 GW of cumulative installed capacity by 2020.

The EC will continue to fund wind energy research and innovation via the Horizon 2020 program. It will support innovation via financial instruments like the European Fund for Strategic Investments (EFSI) and InnovFin Energy Demo Projects (InnovFin EDP) implemented via the European Investment Bank.

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Opening photo: Wind farm in Nordrhein-Westfalen, Germany (Photo credit: Matthijs Soede)

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Finland

1.0 Introduction

Finland's 15-GW winter-peaking power system had 85 TWh of electrical demand in 2016. Renewables provided about 35% of the country's electricity consumption in 2016: 18.4% by hydropower, 12.6% by biomass, and 3.6% by wind power. Installed wind power capacity was 1,533 MW at the end of 2016, generating 3.1 TWh. The target set for 2020 is to generate 6 TWh/yr.

Construction of wind power started growing in Finland in 2012, following 2011 legislation guaranteeing prices for renewable generation. The quota under the guaranteed price scheme—2,500 mega-volt amperes (MVA) of wind power—has been filled, and the projects accepted into the scheme must be built by 1 November 2017.

In 2016, the government published a new National Energy and Climate Strategy for 2030 that introduces a tendering-based subsidy scheme and fulfills the new European Union (EU) guidelines for technology neutrality. Between 2018-2020, production capacity able to generate a total of 2 TWh will be put out to tender. The wind power sector in Finland is estimated to employ 2,000–3,000 people in wind power industry and 2,200 in project development, construction, and operation and maintenance (O&M).

2.0 National Objectives

2.1 Targets

As part of the EU's 20% target, Finland's renewable energy source (RES) goal is 38% of the final energy consumption in 2020. This goal has been achieved with the share of RES in 2016 exceeding 40%. The 2008 Climate and Energy Strategy set a wind power goal of 6 TWh/yr for the year 2020 (6–7% of the total electricity consumption) and the 2013 energy strategy increased the wind power target to 9 TWh/yr by 2025.

In 2016, the National Energy and Climate Strategy for 2030 was published with the following goals:

- Renewables will cover 50% of energy end use
- Energy self-sufficiency will be 55%
- Oil will be reduced by 50% compared to 2005
- Biofuels will cover 30% of transportation
- Coal will be phased out.

Production capacity able to generate a total of 2 TWh of electricity per year will be acquired through a technology neutral tendering process in 2018–2020. The model for operating aid and associated tendering process will be specified in greater detail before tendering. The government will carefully consider societal impacts, including those on businesses, the environment, and human health in these guidelines.

2.2 Policies supporting development

Finland implemented a market based feed-in system with guaranteed pricing, managed by the Energy Authority, in 2011. The guaranteed price for wind power was set at 83.50 EUR/MWh (87.93 USD/MWh) for 12 years. A higher guaranteed price of 105.3 EUR/MWh (110.88 USD/MWh) was available until the end of 2015 to encourage early projects. Producers are paid the guaranteed price minus the three-month average spot price as a premium every three months. The average spot price in the electricity market Nordpool remained low in 2016, at 32 EUR/MWh (34 USD/MWh), versus 30 EUR/MWh (32 USD/MWh) in 2015.

If the average spot price rises above the guaranteed price, no premium will be paid. Should the average spot price drop below 30 EUR/MWh (32 USD/MWh), producers will only get production premiums based on 30 EUR/MWh (32 USD/MWh). During the hours when the spot price is 0 EUR/MWh or less, producers will not get premium payments for that hour—this incentivizes turbines shutting down to help the power system in cases of surplus power production. So far, zero price events have not been seen in Finland. Wind power producers are responsible for paying the imbalance fees from their forecast errors. This adds an estimated 2.0–3.0 EUR/MWh (2.1–3.2 USD/MWh) to the producers, if they use a weather forecast-based prediction system for the day-ahead bids to the electricity market.

In 2016, wind power producers received about 130 million EUR (137 million USD) in premiums, or 50 EUR/MWh (53 USD/MWh) produced by wind turbines in the system. This high premium was due to low level electricity spot prices. If the emission trading of fossil fuel prices raises electricity market prices, this will reduce the payments for this subsidy. There is no special subsidy for offshore wind power. However, an offshore wind power plant demonstration subsidy of 20 million EUR (21 million USD) was given to the Hyötytuuli project in Pori (about 50 MW) in 2014. The project will also receive the guaranteed price system premium.

The Ministry of Economic Affairs and Employment will commission an independent and comprehensive report on the negative health and environmental impacts of wind power before the new operating aid scheme is drafted.

3.0 Implementation and Deployment

Finland's market based feed-in system with guaranteed pricing originally allocated a quota of 2,500 MVA for wind power. In 2015, the government decided to discontinue the subsidy scheme for wind. Before the related legislation was in place, this quota was already filled with applications. By the end of 2016, 1,806 MVA of capacity was in the tariff system, 598 MVA had been accepted to the guaranteed price quota, and 423 MVA was left in the queue but remained outside. The projects accepted in the quota must be ready for grid connection by 1 November 2017 to receive the premium.

After the accepted projects are completed, the Energy Authority estimates that the wind energy production will be 5.0–5.5 TWh in 2018 and cover about 8% of electricity consumption by the early 2020s (6–6.5 TWh annually).

3.1 Progress

The guaranteed price system led to a market of 570 MW/yr in 2016 (182 Turbines)–a record year in Finland. Production from wind power increased 33% to 3.1 TWh in 2016 (50% of the goal for 2020). This corresponds to wind power capacity of 1,530 MW and 3.6% of Finland's annual gross electricity consumption (Table 1, Figure 1).

New wind farms have 1–22 turbines each, with total capacity ranging from 2.3–73 MW and turbines ranging from 2.3–3.3 MW (average: 3.1 MW). The largest wind power plant was erected in Kalajoki. Seventeen turbines totalling 42 MW were removed in 2016. This includes 11 WinWind 3-MW offshore units in Kemi-Ajos, which will be repowered in 2016–2017.

The majority of turbines come from Denmark (49%) and Germany (34%) (Figure 2, left). Individual installed capacity ranged from 75 kW to 5 MW (average: 2.8 MW) and 75% of the total wind power capacity came from turbines with rated power of 3 MW or more (Figure 2, right). This development toward larger turbines is expected to continue in the near future. The majority of turbines come from Denmark (49%) and Germany (34%) (Figure 2, left). Individual installed capacity ranged from 75 kW to 5 MW (average: 2.8 MW) and 75% of the total wind power capacity came from turbines with rated power of 3 MW or more (Figure 2, right). This development toward larger turbines is expected to continue in the near future.

The total offshore capacity is 24 MW and most offshore wind turbines are semi-offshore, located on small cliffs or artificial islands; only one so far is constructed on a caisson. Suomen Hyötytuuli started construction of 50-MW offshore demonstration wind farm on the Finnish west coast. The wind farm is expected to be operable in late 2017. In addition, a 288-MW offshore wind power plant has building permit per the water act, and six more (almost 1,200 MW) have completed environmental impact assessments.

3.2 Operational details

Inland sites have been developed and deployed at an increasing rate since tall turbines with large rotors entered the market. These projects use towers up to 140 m high. High towers and larger rotors provide considerably higher capacity factors—from 20–25% up to 30–40%. The weighted average capacity factor of wind farms operating the whole year was about 27% in 2016 (32% in 2015). The lower capacity factor is due to 2016 being less windy than average; the wind power production index ranged from 92–107% in different coastal areas in Finland, with an average of 95% (compared to 128% in 2015).

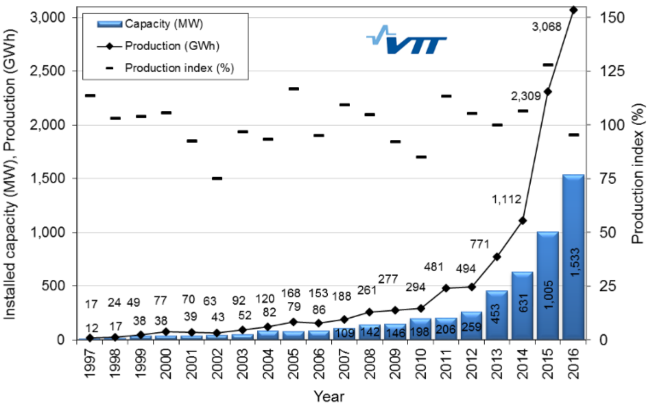

Figure 1. Development of wind power capacity and production in Finland. Production index gives the yearly generation compared to long term average (100%), based on Finnish Meteorological Institute (FMI)

Finland installed a record 570 MW of new wind power capacity in 2016.

3.3 Matters affecting growth and work to remove barriers

Public acceptance of wind power is generally high. According to annual surveys, 81% of Finns support increasing wind production capacity, and over 60% of local decision makers have a positive attitude toward wind power. However, local resistance to projects sometimes slows down development. The Finnish Wind Power Association published guidelines of best practices for project development to improve local acceptance of wind farm projects.

The effects of low-frequency noise and infra sound on health have become an issue in public debate. The study on the health and environmental effects of wind power should be in place before setting up of technology-neutral tendering system for 2 TWh of renewable generation. The main challenge Finland faces in the near future is how to keep the market going in between the current and the new system and all developing projects are anxiously waiting for information on the next system. The government issued a decree on noise limits in 2015, following 2012 noise limit regulations and 2014 guidelines on modeling and measuring the wind turbine noise.

Another public acceptance challenge is the high subsidy in recent years as electricity prices have been low—connected with concerns over the long-term domestic value of a wind farm. To ease planning and permitting challenges, the government enabled easier permitting at industrial sites and added sites for wind power plants in all regional plans. However, the environmental impact assessment process can be lengthy and varies regionally. Some local communities have declined building permits for sites marked in regional plans.

Table 1. Key National Statistics 2016: Finland	
Total (net) installed wind power capacity	1,533 MW
Total offshore capacity	24 MW
New wind power capacity installed	570 MW
Decommissioned capacity	42 MW
Total electrical energy output from wind	3.1 TWh
Wind-generated electricity as percent of national electricity demand	3.6%
Average national capacity factor*	27%
Target	6 TWh/yr in 2020
National wind energy R&D budget	1.6 million EUR (1.7 million USD)

*For wind farms operating for the entire year

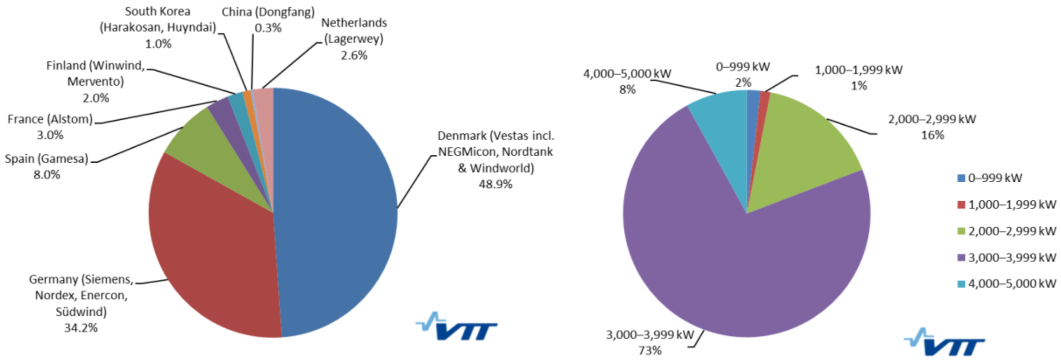

Figure 2. Turbine types (left) and turbine sizes (right) in Finland

The foreseen impact of wind farms on radar systems stopped permitting processes in 2010. The majority of these sites resumed development following procedural and modeling tools for the Ministry of Defense to assess radar impacts. A compensation scheme was also developed to invest in new radar equipment in northern Finland, partial financed by developers.

The Ministry of Traffic and Communication has updated the required distance between wind turbines and roads to 300 m (formerly 500 m). Flight barrier limitations were also updated to 15 km along the runway and 6 km across the runway. In some areas, the height of turbines is limited. The rules for flight obstruction lights at turbine nacelles have been reduced, enabling fewer disturbances to local inhabitants.

In the future, 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

4.0 Impact of Wind Energy

4.1 Environmental impact

Finland's wind power production saves about 2.1 million tons of CO_2 annually, assuming 700 g/kWh CO_2 reduction due to wind power (replacing mostly coal and also some gas power production).

4.2 Economic benefits

Finland's technology sector remains strong, employing 2,000–3,000 people. Development and O&M has led to an increase in direct and indirect employment, with 2,200 jobs reached in 2015. According to Technology Industry's Wind Power Technology Suppliers Group and the Finnish Wind Power Association, these employment figures could double by 2030 if a stable political environment for the deployment of wind energy is maintained.

4.3 Industry development

Many newcomers have entered the Finnish wind power market, including both domestic and foreign investors and project developers. Power companies and local energy works are actively building wind power, and green electricity is offered by most electric utilities. There are more than 100 companies in the whole value chain, from development and design of wind farms to O&M and other service providers, with the majority in the planning and construction of wind farms domestically.

Finland's 2020 target for renewable energy sources (RES) has already been achieved, with RES share exceeding 40% in 2016.

More than 20 technology and manufacturing companies are involved in wind power in Finland. Several industrial enterprises have become global suppliers of major wind turbine components. 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, Finland produces many materials prominent wind turbine manufacturers, such as cast-iron products and tower materials (SSAB, formerly Rautaruukki), and glass-fiber products (Ahlstrom Glasfiber). 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. After the bankruptcy of both WinWind and Mervento, there is no longer a domestic turbine manufacturer in the market.

A growing number of companies offer operation and maintenance services in Scandinavian and Baltic markets, including Bladefence, JBE Service, and Wind Controller. Norsepower is the leading provider of low-maintenance, software-operated and data-verified auxiliary wind propulsion systems.

5.0 R,D&D Activities

5.1 National R, D&D priorities

The Finnish Funding Agency for Technology and Innovation (Tekes) is the main public funding organization for research, development, and innovation in the country. Finland has not had a national research program for wind energy since 1999. Tekes funds individual industry-driven projects and the public funding level for wind power R&D projects in 2016 was around 1.6 million EUR (1.7 million USD) (Figure 3). Ongoing wind power related R&D projects are mostly industrial development projects.

Financing in 2016 consisted of five projects, the most interesting of which is the Norsepower rotor-sail project. The 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

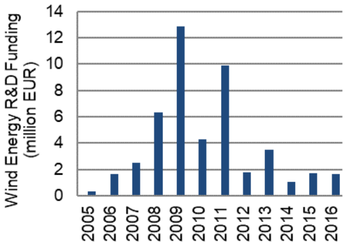

Figure 3. National R&D funding for wind energy related projects by Tekes

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 also carry out R&D projects related especially to electrical components and networks (Aalto, Lappeenranta, Tampere, and Vaasa).

The Finnish Wind Power Research Network (FinWindResearch) is an ecosystem of wind power experts established in 2016 for the purposes of information exchange, cooperation, and new innovations. FinWindResearch currently operates on a voluntary basis and consists of more than 30 members from over ten Finnish research institutes. As a catalyst for new innovations, FinWindResearch organizes a yearly seminar for all Finnish wind power experts to network and exchange information. The network plans to host other events, such as web-based workshops, in the future.

5.2 Research results

In 2016, VTT launched the world's first online, free global icing and low temperature atlas at www.vtt.fi/sites/wiceatlas. WiceAtlas is especially useful for identifying icing risks when planning new wind farm projects.

The research programme on Flexible Future Energy Systems FLEXe provided results relevant for wind integration. For example, quantifying the changes in flexibility needs for North European power markets with large shares of wind and solar (http://flexefinalreport.fi/).

5.3 Collaborative research

VTT has been active in several international projects in the EU, Nordic, and IEA frameworks. In 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, 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 actively participates in joint programs on wind energy and smart grids. Finland also takes part in the following IEA Wind TCP 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)

6.0 Next Term

Finland expects to install nearly 600 MW of new capacity in 2017. The development in 2018–2020 will depend heavily on the launch and process of the upcoming technology-neutral tendering. Meanwhile, some of the developed projects have applied for a special investment grant that is available for renewable technology projects with new technology innovation. Projects totaling 12,900 MW are currently being developed. The 50-MW offshore demonstration to be completed in 2017 has a reserved place in the quota.

Overcoming cold climate limits is essential to wind power development in Finland. A blade heating system developed at VTT is now in commercialization; a spin-off from VTT, Wicetec, began activities in 2014. Further research and development in this area will continue in 2017.

References:

Opening photo: View from Tervola wind farm, Finland (Photo credit: Tuuliwatti Oy)

Authors: Esa Peltola, Simo Rissanen, and Hannele Holttinen, VTT Technical Research Centre of Finland, Finland.

France

1.0 Introduction

Wind power is a significant renewable source of electricity production in France—second only to hydroelectricity. 2016 has been France's best year in terms of industry development, with over 1.3 GW of new installed wind power capacity. These installations bring the country's total land-based installed wind power capacity to approximately 11.7 GW.

The record installation rates are the result of simplified administrative procedures and better visibility in terms of regulatory changes. The annual electrical energy output from wind was 20 TWh, a decrease from 2015 despite higher installed power capacity, due to unfavorable wind conditions. Wind and all renewables covered 4.3% and 19.6% of national electricity demand, respectively.

Offshore wind also saw continued support in 2016, with the first phase of a competitive dialogue for a third tender in the Dunkerque area, as well as a preparation of a new tender in the Oléron area. The call for tenders for floating wind pilot farms also concluded in 2016, awarding three farms in the Mediterranean and one in the Atlantic.

2.0 National Objectives

France defined new trajectories for renewables after adopting the Energy Transition for Green Growth Act in 2015. This law defines long-term objectives for the transition to a low-carbon economy and energy system, and also defines new policy tools. It addresses several aspects including energy efficiency, renewables deployment, and the future of nuclear energy.

2.1 Targets

To set renewable energy targets for 2018 and 2023, the Pluriannual Energy Program (Programmation Pluriannuelle de l'Energie, PPE) was updated during 2015 and 2016. New trajectories for each renewable energy source are defined in the PPE, leading to the following targets for installed renewable power capacity. By the end of 2018:

- 15 GW land-based wind power capacity
- 0.5 GW fixed offshore wind power capacity
- 10.2 GW solar energy
- 25.3 GW hydroelectricity

By the end of 2023:

- 21.8–26.0 GW land-based wind
- 3 GW fixed offshore wind, with between 0.5–6.0 GW of ongoing projects, depending on the outcome of the first projects and price levels
- 18.2–20.2 GW solar energy
- 25.8–26.05 GW hydroelectricity
- 100 MW of installed tidal floating wind and wave, with between 200–2,000 MW of ongoing projects, depending on the outcome of the first pilot farm projects and price levels

2.2 Policies supporting development

The introduction of the "Complément de rémunération" in 2016 marked a significant evolution of the regulatory framework. When generators sell their electricity directly in the market, they will receive these feed-in premiums in addition to the market price.

In agreement with the European Commission guidelines, the new scheme applies to projects requesting full power purchase agreements or a feed-in premium during 2016, and to all wind farms elected through a formal tender process as of 2017. A multiannual tender for 3 GW of new installed wind power capacity is planned with a yearly target of 1 GW distributed along two sessions.

Additionally, a competitive dialogue has been initiated to allow cost reduction in the offshore area of Dunkerque for the third offshore tender, while several preliminary studies in terms of wind resource assessment will be launched in the Oléron sector.

3.0 Implementation and Deployment

3.1 Progress

France achieved a record value of 1,350 MW of new wind power capacity in 2016, leading to a total of 11.7 GW of installed capacity. Despite this significant increase, a poor wind resource significantly affected wind-generated electricity. Production in 2016 was reduced to 20 TWh, and the percentage of electricity demand met by wind energy remained at 4.3%.

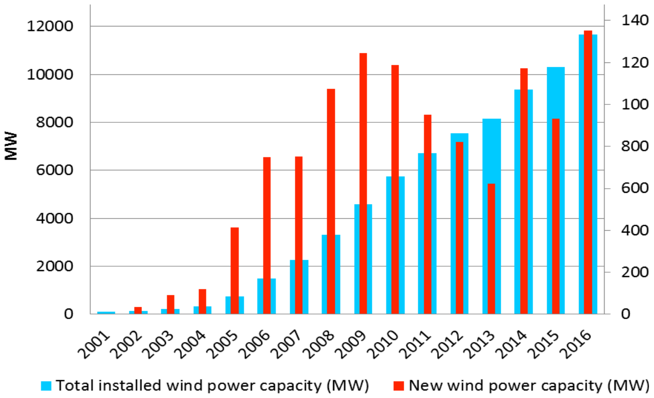

Figure 1. New and total wind power capacity in France from 2001–2016

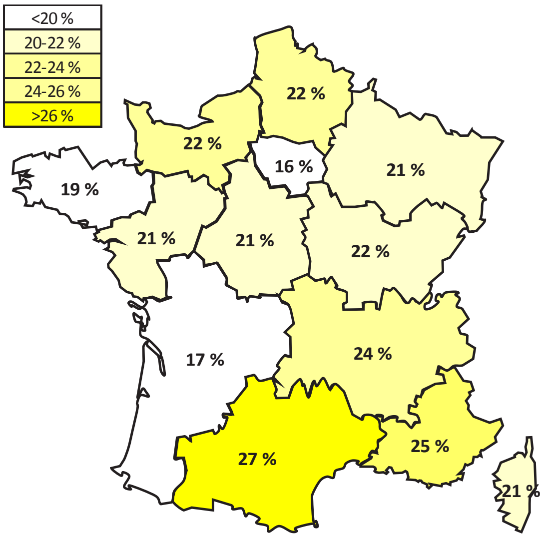

Figure 2. Capacity factors during 2015 per region

Despite a very high installation rate, a yearly value of 1.65 GW of new wind power capacity will be needed to reach the 2018 target set by the PPE.

3.2 Operational details

The annual wind-generated electricity production decreased in 2016, despite a very active year for installations. The average capacity factor is estimated at 21.7%, which is significantly lower than the 2015 value of 24.3%.

The average wind turbine nameplate capacity is currently 2.3 MW with a nacelle height of 80–90 m [1]. However, there is a trend toward higher nacelle heights (typically 100–110 m) with an increased swept area, which can be used to improve economics in areas with lower average wind speeds. For the standard wind turbine type, the average levelized cost of energy ranges from 54–108 EUR/MWh (57–114 USD/MWh), but can decrease to 50–94 EUR/MWh (53–99 USD/MWh) [1].

3.3 Matters affecting growth and work to remove barriers

The Energy Transition for Green Growth Act confirmed an already ongoing trend for simplification of the permitting and licensing process. The act also introduced new measures, which plan to:

- Suppress "Wind Development Areas" (Zones de Développement de l'Eolien, ZDE) and the rule of five turbines (defining a minimum number of wind turbines per installation) as part of the French law for Energy transition (number 2013-312)
- Extend land-based wind environmental and construction permits up to ten years
- Approve the single authorization process ("one stop-shop" approach) that was extended to the whole territory in 2015 after being tested in several administrative regions
- Reduce deadlines for appeals within this single authorization process
- Implement incentives for residents to acquire shareholdings in limited companies involved in local renewable energy projects

With over to 1.3 GW of new wind power capacity installed, 2016 has been the best year in France in for wind industry development.

4.0 Impact of Wind Energy

4.1 Environmental impact

Wind energy provided approximately 25% of the overall installed renewable power capacity in France, which amounted to 45.8 GW at the end of 2016. This constituted the second largest source after hydroelectricity. In terms of electricity production, wind contributed to 22% of the total renewable production.

4.2 Economic benefits

Wind energy provided 10,000–11,000 direct jobs and nearly 8,000 indirect jobs [3]. Manufacturing of wind turbines and components account for an estimated 6,700 employees. Though there is no major wind turbine manufacturer in France, several players such as DDIS, Vergnet, and more recently Poma Leitwind, contribute to the French economy.

A variety of suppliers already exist, such as Nexans for the electric cables, Leroy-Somer for generators, and Rollix for blade and yaw bearings. Several small to medium enterprises (SMEs) are also providing advanced technologies; for example, LeoSphère is a leading lidar provider, while METEODYN and METEOPOLE provide service and software for wind resource assessment. This situation is currently evolving quickly, along with the development of a local offshore industry.

The national land-based wind market is valued at 1.8 billion EUR/yr (1.9 billion USD). Of this total, 1.3 billion EUR (1.4 billion USD) are devoted to investment in new parks, and 5.0 million EUR (5.3 million USD) are intended for the operation and maintenance of existing wind turbines.

Table 1. Key National Statistics 2016: France

Total (net) installed wind power capacity	11,700 MW
Total offshore capacity	0 MW
New wind power capacity installed	1,380 MW
Decommissioned capacity	0 MW
Total electrical energy output from wind	20 TWh
Wind-generated electricity as percent of national electricity demand	4.1%
Average national capacity factor	21.7%
Target	15 GW land-based and 0.5 GW offshore by 2018
National wind energy R&D budget	N/A

4.3 Industry development

Global concentration in the wind energy sector lead to several evolutions for French wind turbine offshore manufacturers during 2016. After General Electric (GE) acquired LM Windpower and Alstom's wind energy division, the company confirmed that a new blade manufacturing facility would be created in France. Additionally, GE would develop industrial facilities for offshore wind turbine manufacturing near Cherbourg (Normandy).

A merger between GAMESA and Siemens was also announced in 2016. AREVA, the second shareholder with GAMESA of ADWEN, allowed GAMESA to acquire its stakes, thus leading to full transfer of ADWEN to GAMESA/Siemens.

Continuing its development in offshore wind, STX France confirmed its position as a strong provider of jacket substations, contributing also to the development of jacket foundations for offshore wind.

5.0 R,D&D Activities

5.1 National R,D&D priorities

The development of offshore wind and large wind turbine technology has been a priority in the recent years. The French Environment and Energy Management Agency (ADEME) is the driving funding agency for applied R,D&D projects in the area. ADEME funds and administrates three kinds of projects: PhD theses; R&D projects for intermediate technology readiness levels (TRL); and the Programme des Investissements d'Avenir, dedicated to industrial projects, and funded by subsidies, reimbursable aids, and possibly equity.

After a call for proposals in 2009 on ocean energies which included floating wind technologies, another call was launched in 2013 and four industrial demonstration projects were awarded by ADEME (see the *IEA Wind TCP 2015 Annual Report*).

Among the selected topics, floating wind technology was identified as a strategic area. France has a favorable situation for floating wind, local harbor facilities, and a local naval and offshore oil and gas industry capable of addressing this market. Besides the three individual Vertiwind, SeaReed and OceaGen demonstration projects, a dedicated call for tender for floating wind pilot farm projects highlighted the focus on floating wind.

5.2 R&D budget

Even though no national statistics are emitted on R&D budget, 2016 has been a very active year, with the allocation of budget of the four floating-wind pilot farm projects.

5.3 Research results

The EOLIFT project, funded by ADEME and led by Freyssinet, proposes the development of innovative pre-stressed wind turbine concrete towers for high power (more than 3 MW) and large height (more than 100 m), incorporating lifting equipment to avoid using high-capacity cranes. The proposal aims to increase the speed of wind turbine farm construction and to reduce costs related to the tower and foundation by 15%. This project was successfully concluded in 2016 with the construction of a demonstration project in Brazil with 120-m tall towers.

5.4 Test facilities & demonstration projects

In 2016, the dedicated call for tender for floating wind pilot farms concluded and four projects were awarded. The call required projects to have three to six high-power (equal or greater than 5 MW) wind turbines, to be in four predesignated areas.

Four projects were awarded to the following consortia:

- The Faraman project (near Fos sur Mer, in the Mediterranean), led by EDF Energies nouvelles, which comprises three Siemens 8-MW wind turbines on a floater developed by SBM Offshore and IFP Energies nouvelles
- The Groix and Belle-Île project (on the Atlantic Coast), led by EOLFI and CGN Europe, which features four GE Haliade 6-MW wind turbines on a floater developed by DCNS
- The EoldMed project (near Gruissan in the Mediterranean), which will use four Senvion 6.15-MW wind turbines on a floating foundation developed by IDEOL
- The fourth project, led by Engie, Caisse des dépôts, EDPR and Eiffage (near Leucate in the Mediterranean), which will host three GE Haliade 6-MW wind turbines on a floater designed by Principle Power and built by Eiffage

All four projects intend to begin around 2020 and were granted CAPEX funding (pending to the notification to the EC) under the form of direct subsidies, and a reimbursable loan, along with a feed-in tariff.

5.5 Collaborative research

Since joining IEA Wind TCP in 2014, nearly 15 French organizations, including private companies, Regional Transmission Organizations (RTO), SMEs, and laboratories, have expressed interest in collaborative research. France has contributed to the following IEA Wind TCP Tasks with positive results:

- Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power
- Task 29 Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models (Mexnext III)
- 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
- Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN)

Participation in Task 36 Forecasting for Wind Energy is also being considered.

6.0 Next Term

After seeing a modification of its regulatory framework and new objectives, the trend toward land-based installations will likely continue in 2017. A third round for fixed offshore wind has been initiated and will continue, though floating wind continues to see increased interest.

The four selected floating wind demonstration projects should start their engineering work in 2017. France's involvement in IEA Wind TCP tasks is also expected to continue at the same level.

References:

Opening photo: Wind farm in the French countryside (Photo credit: Maia Eolis)

[1] Ministère de l'environnement, de l'énergie et de la Mer, en charge des relations internationales sur le climat. ADEME. December 2016. Coûts des énergies renouvelables en France. Edition 2016. ADEME editions.

[2] Ministère de l'environnement, de l'énergie et de la Mer, en charge des relations internationales sur le climat. February 2017. Tableau de bord: éolien. Quatrième trimestre 2016. Download from: www.statistiques.developpement-durable.gouv.fr

[3] ADEME, 2017. Etude sur la filière éolienne française: bilan, prospective et stratégie. Partie 1.

Authors: Daniel Averbuch, IFPEN Energies nouvelles; and Sakina Mouhamad, Ministère de l'Environnement, de l'Energie et de la Mer (DGEC), France.

Germany

1.0 Introduction

Renewable energy meets one-third of Germany's national electricity demand, with the largest share coming from wind-generated electricity. Germany has 28,217 wind turbines, which account for nearly 50 GW of installed capacity. In 2016, the new installed capacity was 4,993 MW, compared to 5,927 MW in 2015. New offshore wind power capacity declined, as expected, with an installed capacity of 4.15 GW in 2016. Due to a rather weak wind year, Germany's wind sector produced 77.4 TWh of wind-generated electricity, compared to 79.2 TWh in 2015. The Renewable Energy Act (EEG 2017) was amended in 2016 and led to the first auctions in 2017.

R&D efforts continue to focus on increasing wind energy yields and reliability, as well as reducing costs. Projects seek to optimize production processes and develop taller towers and longer rotor blades for land-based wind energy. Offshore wake effects from the interaction between individual wind turbines and offshore windfarms are being studied, as are reducing the load on components, modifying drive trains, and increasing lifespans. In 2016, three research projects for setting up research oriented new test sites were approved in flat and complex terrain [1-8].

2.0 National Objectives

2.1 Targets

In 2016, the Renewable Energy Act (EEG 2017) defined national wind energy objectives. For land-based wind, Germany expects to install 2.8 GW/yr from 2017-2019 and 2.9 GW/yr after 2020. Offshore capacity is expected to reach 15 GW by 2030 (0.5 GW/yr in 2021 and 2022, 0.7 GW/yr from 2022-2025, and 0.84 GW/yr from 2026 on). Land-based pilot R&D turbines with a capacity of up to 125 MW/yr are exempted of the obligatory call for bids within the EEG 2017 [9].

2.2 Policies supporting development

The EEG 2017 was adopted on 8 July 2016 and became operative on 1 January 2017. With the first auctions and tenders in 2017, wind energy deployment began a new era. The first offshore auctions for 1.49 GW in the German Exclusive Economic Zone's North Sea Cluster concluded in April 2017 with the lowest bid of 0.00 EUR/kWh and the highest of 0.06 EUR/kWh (0.063 USD/kWh). On average, the bidding price amounted to 0.0044 EUR/kWh (0.0046 USD/kWh). Grid connection costs were not included in the bidding price in Germany because grid connection is provided by the transmission system operators [6].

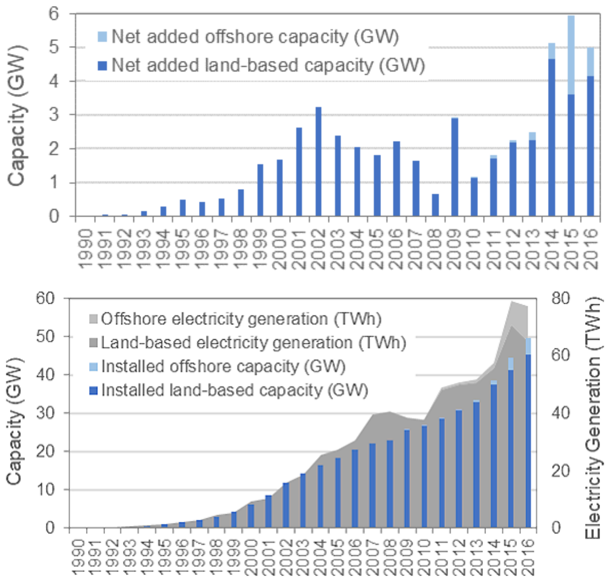

Figure 1. Net added wind power capacity, installed wind power capacity and wind-generated electricity (Source: AGEE-Stat, Deutsche WindGuard GmbH)

Land-based community energy wind projects were also successful during the first auction in spring 2017, where 93% of bidders were granted the tender [7].

3.0 Implementation and Deployment

3.1 Progress

Installed land-based power capacity reached 45.38 GW (41.24 GW in 2015) and offshore capacity increased from 3.30 GW in 2015 to 4.15 GW in 2016 (Figure 1). Net new land-based installations (4.140 GW) were the second highest in German history (4.651 GW in 2014) with a 14% increase compared to the previous year—marking a successful year for the wind energy technology sector.

In 2016, Germany installed 853 MW of offshore wind power capacity. While this is only 37% of the capacity installed in 2015 (2.303 GW), it does contribute to the national offshore target (Figure 2) [1, 4, 7]. Land-based wind electricity generation declined from 70.92 TWh in 2015 to 65.05 TWh in 2016, largely due to moderate wind conditions. Offshore wind-generated electricity could not fully compensate for this drop, although it contributed with 12.37 TWh (8.28 TWh in 2015). A relatively low land-based and offshore combined capacity factor of 18.8% reflects this decline [1, 4].

3.2 Operational details

The average project size for land-based wind parks connected in 2016 was 9.6 MW; the largest consisted of 19 turbines with a total rated capacity of 61.4 MW. The tallest wind turbine connected in 2016—a Nordex N131/3300 in Hausbay, Rhineland-Palatinate—has a hub height of 164 m, a rotor diameter of 131 m, and a total height of almost 230 m, according to the original equipment manufacturer.

The manufacturer reached this height using a hybrid tower consisting of 100 m concrete and two steel tower segments.

The Lower Saxony-based manufacturer Enercon has introduced another form of hybrid tower that uses cylindrical and conical concrete elements to erect towers of different heights, simplifying production and reducing project costs [2, 7, 10, 11].

Offshore, three projects or parts of them were connected in 2016: Gode Wind I (334.52 MW), Gode Wind II (263.09 MW) and Sandbank (240.0 MW) (Figure 2). Sandbank will use in total 72 Siemens SWT-4.0-130 turbines (4.0 MW), Gode Wind I and II use a total of 97 Siemens SWT-6.0-154 turbines (6.264 MW) [3, 7].

3.3 Matters affecting growth and work to remove barriers

Starting in 2017, central tenders will determine land-based and offshore wind power capacity. This major change in the incentive system led to strong installation numbers in 2016. Additionally, many permits were able to qualify for the old feed-in tariff system. As of 31 December 2016, permits for 4.7 GW wind power capacity were approved, which should significantly increase wind power capacity in 2017 [2, 7].

4.0 Impact of Wind Energy

4.1 Environmental impact

In 2016, wind energy generated 77.4 TWh of electricity in Germany [1, 4]. This meets 13% of the national electricity demand and avoids 52.5 million tons of CO_2 equivalents.

State of the art techniques were used to reduce noise impacts (e.g., big bubble curtains) from pile driving for offshore wind turbine foundations [5].

Erlangen-Nuremberg University developed a software tool called “ProBat” within the research project RENEBAT III. Using bat activity data from a turbine's nacelle and respective wind speed data, "ProBat's" curtailment algorithm determines the cut-in wind speeds for bat-friendly operation at land-based wind turbines. The software also identifies the estimated revenue losses due to each bat-specifically curtailed operation [12].

4.2 Economic benefits

Wind energy investments dominated renewable energies in Germany in 2016, with two thirds allocated to wind energy. In 2016, wind energy outlays totaled 11.33 billion EUR (11.93 billion USD), of which 9.18 billion EUR (9.67 billion USD) was investment and 2.15 billion EUR (2.26 billion USD) was for operation. Land-based wind energy represented the main share.

Projects in the land-based sector accounted for most cost reductions. These projects cost approximately 1.450 EUR/MW (1.527 USD/MW), including only 2016 investment costs and gross added wind power capacity. Offshore, the estimated project costs amounted to 3.872 EUR/MW (4.077 USD/MW), including investment costs from 2008–2016 and total added wind power capacity by the end of 2016 [4].

4.3 Industry development

Wind energy industry continued to consolidate in 2016. With clearance from the competition authorities, the Nordex Group and Acconica Windpower merged into one company. Nordex also announced a partnership with Lufthansa Aerial Services for drone-supported wind turbine inspection with a focus on rotor blades.

Shareholders for Spanish wind turbine manufacturer Gamesa ratified the company’s merger with Siemens Wind Power. This cleared the way to merge into the world’s biggest wind turbine manufacturer, with an installed wind power capacity of approximately 70 GW. Wind turbine manufacturer Senvion acquired rotor blade manufacturer Euros, which included acquiring the blade, mold, and master plug manufacturing facility in Poland.

New land-based installations accounted for 4.140 GW in 2016—the second highest amount in German history, marking a successful year for the wind energy technology sector.

Aurich-based Enercon announced that they will develop new business ideas around renewable energies and smart grids with the utility EWE. The companies will test new technical solutions in northwest Germany, and then standardize them throughout other regions. Enercon has also reorganized its management and some other divisions, especially the research related ones.

5.0 R,D&D Activities

In autumn 2016, renewable energy research networks were established for wind energy and photovoltaics. The wind energy research community, including industry representatives and political stakeholders, began cooperating through different topical working groups, including land-based and offshore technical committees. These research networks encourage dialogue between wind energy stakeholders, including comprehensive questions of the Wind Energy Research Policy [5, 8].

5.1 National R,D&D priorities

According to the federal government’s Sixth Energy Research Programme, the energy sector’s R&D priorities focus on renewable energies, the wind energy value chain, social acceptance, and the effects of wind energy on land and marine environments. The current program aims to align the goals of the German Energy Transition with project funding for wind energy-related R&D topics. The Federal Ministry for Economic Affairs and Energy started development of the Seventh Energy Research Programme in autumn 2016 [8].

The federal government also launched a “Digital Agenda for the Energy Transition” (SINTEG) in 2016. Through its five “Smart Energy Showcases,” this agenda aims to develop and demonstrate exemplary solutions for a climate-friendly, secure, and efficient energy supply with

Table 1. Key National Statistics 2016: Germany

Total (net) installed wind power capacity	49,534 MW
Total offshore capacity	4,150 MW
New wind power capacity installed	4,993 MW
Decommissioned capacity	262 MW
Total electrical energy output from wind	77.4 TWh
Wind-generated electricity as percent of national electricity demand	13%
Average national capacity factor	18.8%
Target	Land-based: 2.8 GW/yr 2017-2019; 2.9 GW/yr from 2020; Offshore: 15 GW by 2030
National wind energy R&D budget	93.37 million USD (88.70 million EUR)

Germany

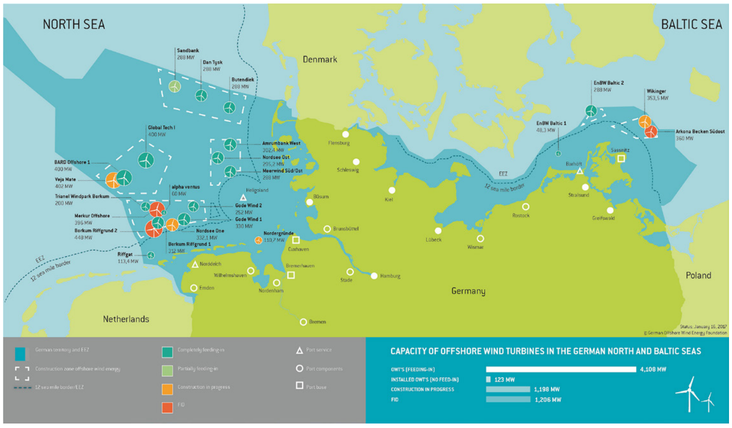

Figure 2. Offshore wind energy in Germany in 2016 (Source: Stiftung OFFSHORE-WINDENERGIE)

high proportions of intermittent electricity generation on the basis of wind and solar energy in large model regions [13].

5.2 R&D budget

The R&D funds by the Federal Ministry for Economic Affairs and Energy (BMWi) on wind energy amounted to 86.2 million EUR (90.77 million USD) for 93 new projects (Figure 3). Four other projects received 2.47 million EUR (2.6 million USD) as updated funds. In total, BMWi spent 88.67 million EUR (93.37 million USD) 2016 for 97 projects. The 322 ongoing wind energy-related projects in 2016 made a funds flow of 49.7 million EUR (52.33 million USD). All of these projects have an emphasis on application-oriented research.

5.3 Research results

R&D efforts in Germany include application-oriented R&D projects regarding mechanical component research, offshore logistics with cost-effective transport solutions and modularized components, and wind turbine noise.

The **"PTB Wind"** project, which has received 9.4 million EUR (9.9 million USD) in funding from BMWi, is developing new measuring instruments, application-oriented specimens, and new measuring and testing procedures by:

- Building a large coordinate measuring machine for the dimensional measurement of drive train and other major wind turbine components (measurement volume of up to 5 m x 4 m x 2 m)
- Planning a torque standard machine up to 5 NM•m for static and dynamic loads on transfer standards with future expandability up to 20 NM•m
- Developing a mobile and robust wind LIDAR system for detecting wind profiles over 200 m, even in difficult terrain, with a high resolution and a recirculation on SI-units

BMWi is funding the **"SmartBlades2.0"** project with 14.3 million EUR (15.06 million USD). German research partners are working with the U.S. National Renewable Energy Laboratory (NREL) to:

- Test and demonstrate four defined technologies in field and wind tunnels
- Validate tools and methods for industrial requirements and utilization
- Enhance relevant and promising methods and concepts
- Determine the benefits and drawbacks of smart blades technologies

The **"TremAc"** project analyzes acoustic and seismic wave propagation with dynamic interaction of tower structure, foundation, subsoil and topography. The project aims for social acceptance over noise issues of wind turbines by evaluating thresholds and protective measures, comparing findings with environmental medicine and psychology, and making recommendations from a technical viewpoint. The project plans to communicate with public authorities, the scientific community and the public. The BMWi is funding this project with 1.9 million EUR (2.0 million USD) [5].

The Federal Ministry of Education and Research (BMBF) also supports basic oriented material research and deals with topics like white edging cracks on wind turbine bearings and anti-icing coating for rotor blades [5].

5.4 Test facilities & demonstration projects

In May 2016, the **"FVA Gondel"** project installed a modified 2.75-MW turbine on the 4-MW nacelle test facility of the Center for Wind Power Drives (CWD) at Aachen University RWTH. This facility uses load sensing equipment and numerical model simulations to analyze and validate local drive train strains on an open access base for the researchers and industry partners of the project.

Three new test facilities received funding in 2016:

- **Test Field Bremerhaven** at Fraunhofer IWES Northwest provides a next-generation wind turbine as a research platform for free-field measurements and validation on the DyNaLab nacelle test bench; funded with 18.5 million EUR (19.5 million USD) by BMWi, 2016-2019
- German Research Platform for Wind Energy **(DF Wind)** at Research Alliance Wind Energy FVWE, which bases on first design developments in the years 2013 and 2014, includes two multi-MW wind turbines (2.5–3.5 MW), one 500-kW experimental turbine, four meteorological masts (100–150 m), and additional R&D infrastructure at a location in Northern Germany; 9.1 million EUR (9.58 million USD) of funding by BMWi, 14 million EUR (14.74 million USD) by the Federal State of Lower Saxony, 2016-2019

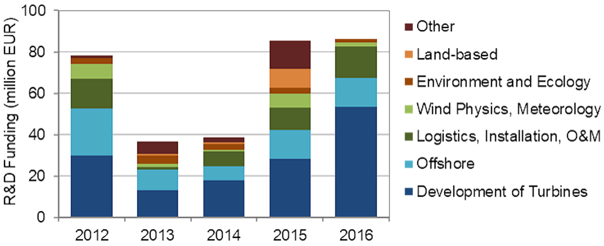

Figure 3. Development of German R&D funds from 2012–2016 (Source: Federal Ministry for Economic Affairs and Energy BMWi, Layout: IEA Wind TCP)

- Wind Science and Engineering Test Site **(WINSENT)** of the Southern German Wind Energy Research Cluster WindForS includes two 750-kW experimental turbines, four 100-m meteorological masts, and additional R&D infrastructure; funded with 10.4 million EUR (10.95 million USD) by BMWi, 1.2 million EUR (1.26 million USD) by the Federal State of Baden-Württemberg, 2016-2020

5.5 Collaborative research

BMWi is Germany's contracting party in the IEA Wind TCP. German research institutions and industry representatives were attending 14 of 15 active research tasks at the end of 2016. All of Germany's Task participants are also executing national funded projects in their related topics, which benefits the visibility of German institutions on the worldwide information exchange.

German institutions lead Task work as operating agents in several cases, including 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 35 Full-Size Ground Testing for Wind Turbines and Their Components.

Germany is also involved in the European Commission's Strategic Energy Technology Plan and takes part in the offshore wind energy temporary working group. German industry and research representatives contribute to the European Technology and Innovation Platform (ETIPWind), support the European Energy Research Alliance (EERA), and take part in the European Academy of Wind Energy (EAWE).

The "Framework Programme 7" is currently working on several European-funded wind energy projects, as well as "Horizon 2020," which includes a highly motivated contribution of German participants. Furthermore, the German federal government is enabling bi- and multilateral research projects via the so called "Berlin-Model".

German researchers are also working within one European Research Area (ERA) Net Plus called "NEWA – New European Wind Atlas". At the moment, Germany is not contributing to any existing wind energy-related ERA-NET co-funds.

6.0 Next Term

Wind energy remains a main pillar for the German Energy Transition. Germany plans to continue participating in the IEA Wind TCP, and German institutions intend to take part in prolonged and new research tasks within the next term. The 2017 elections for the German parliament might indicate how the federal government will underline the energy transition process in the future.

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Opening photo: Wind turbines in the morning sun near Düren, North Rhine-Westphalia, Germany (Photo credit: Franciska Klein)

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Greece

1.0 Introduction

In 2016, Greece had its second best year for wind energy. The country installed 238.55 MW of new wind power capacity (Table 1 and Figure 1). According to the Greek Wind Power Energy Association (ELETAEN), this 8.7% increase brings the total installed wind capacity to 2,374.3 MW [2].

The electrical output from wind generation in Greece totaled 4.3 TWh and wind generation as a percent of the national electric demand was approximately 8.4% [1].

At the close of 2016, a total of 179 wind farms were operating in Greece [3]. Greek wind energy still needs to increase significantly in order to reach the target of 7,500 MW by 2020 set by the National Renewable Energy Action Plan.

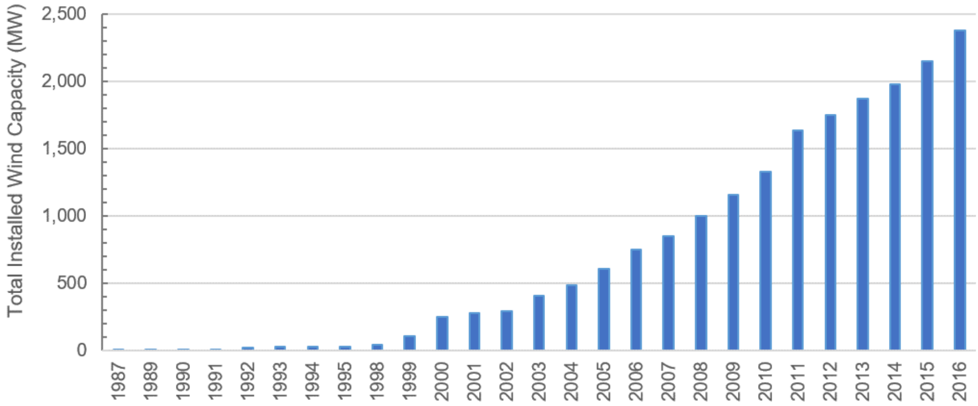

Figure 1. Total installed wind capacity in Greece 1987–2015 (Source: HWEA)

References:

Opening photo: Skopies wind farm (Courtesy: Iberdrola)

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Table 1. Key National Statistics 2016: Greece	
Total (net) installed wind power capacity [a]	2,374 MW
Total offshore capacity	0 MW
New wind power capacity installed	239 MW
Decommissioned capacity	---
Total electrical energy output from wind	4.3 TWh
Wind-generated electricity as % of national electricity demand	8.4%
Average national capacity factor	---
Target	7,500 MW by 2020
National wind energy R&D budget	---
[a]Hellenic Wind Energy Association (HWEA) Wind Energy Statistics 2016 [2] [b]ENTSO-E [1]	

Ireland

1.0 Introduction

In 2016, Ireland's wind energy sector saw continued and steady growth. The total installed wind power capacity grew to 2,800 MW—an increase of 345 MW compared to 2015. This represents a new record for annual capacity addition, exceeding the previous peak of 270 MW in 2014.

As part of their commitment to the 2020 national renewable electricity target, the Irish government supported robust growth in deployment by extending deadlines for the Renewable Energy Feed-in Tariff (REFIT) II support scheme. Yet despite the strong growth, the percentage of electricity demand met by wind to fell to 20.9% and wind-generated electricity curtailment levels fell to 2.8% in 2016. This was largely due to a low wind year and increasing electricity demand.

An ongoing national R,D&D effort enables wind energy to achieve continued growth, particularly on grid integration issues. For example, the Delivering a Secure, Sustainable Electricity System (DS3) program executed by the Irish Transmission System Operator (TSO), EirGrid, has brought changes to electricity system operation, allowing an increased limit on the maximum instantaneous wind energy penetration [1].

Obtaining acceptance of new wind energy projects by host communities remains a challenge. The government has prioritized the introduction of measures and practices to improve this, supporting their measures with robust research.

2.0 National Objectives

2.1 Targets

Under the 2009 EU Renewable Energy Directive, Ireland is legally bound to meet a target of 16% of its total energy demand from renewable energy sources by 2020. Crucially, 40% of electricity demand is to be met with 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 with land-based wind energy. Wind energy will also contribute approximately 7% of total energy demand, making up nearly half of the overall 16% national renewable energy target [2].

A 2016 generation capacity review identified that, due to a projected increase in electricity demand, Ireland must increase wind-generated electricity 3,800–4,100 MW by 2020 to achieve 40% renewable electricity [3]. This will require an average of 1,150 MW of new wind power capacity to be added over the next four years. This requirement may increase with further upward revision of demand projections.

2.2 Policies supporting development

The primary support scheme for renewable electricity in Ireland is the REFIT scheme, which has been in place since 2006 [4]. Applications for the 2012 REFIT 2 scheme closed in December 2015. In December 2016, the government extended the required 'connected' date for projects from 31 December 2017 to 31 December 2019 and extended the requirement to have a Power Purchase Agreement (PPA) in place from 30 September 2018 to 31 March 2020 [5].

The increasing amount of wind energy and falling wholesale electricity prices (including depression of prices by wind power) have contributed to an increase in the consumer levy. The projected cost of a consumer levy for supporting all renewable electricity output from 2015-2016 was approximately 156.4 million EUR (164.7 million USD); over 90% of that cost supported wind energy [6].

The inflation-adjusted REFIT tariffs for wind in 2015 were 69.72 EUR/MWh (73.42 USD/MWh) for wind farms larger than 5 MW and 72.167 EUR/MWh (75.992 USD/MWh) for wind farms smaller than 5 MW [7].

Given the closure of the REFIT II scheme, the government initiated the high-level design of a replacement Renewable Electricity Support Scheme in 2016 [8]. The Department of Communications, Climate Action, and Environment (DCCAE) advertised a Request for Tender (RfT) for an "Economic Analysis to Underpin a New Renewable Electricity Support Scheme in Ireland." The Sustainable Energy Authority of Ireland (SEAI) also tendered for a study on models for community renewable energy schemes in October 2016 [9, 10].

3.0 Implementation and Deployment

3.1 Progress

The increase of 345 MW during 2016 represents a new record for wind farm construction, with the total generating capacity growing to 2,800 MW. Due to a low wind year and increasing electricity demand, the percentage of electricity demand met by wind fell in 2016. The 6.15-GWh output marked a decrease of 6.4% from 2015 and accounted for 20.9% of 2016 electricity demand (compared with 22.8% in 2015).

Wind-generated electricity curtailment levels fell to 2.8% in 2016—down from 5.1% in 2015 despite increases in installed wind power and protracted Ireland-GB interconnector outages [11]. However, wind remained the second largest source of electricity generation after natural gas.

Ireland intends to meet 40% of its electricity demand from renewable energy by 2020. Normalized, wind energy contributed to 22.3% of electricity demand in 2016, and the total renewable contribution was 26.5% (compared to 21.1% and 25.3% respectively in 2015). Thus, while wind output fell in 2016, the normalized statistics continue to show progress towards targets.

3.2 Operational details

Several of the largest potential projects in Ireland contributed to the country's record year for annual new wind farm capacity. The 95-MW Meenadreen Wind Farm, with 38 Nordex N90/2500 2.5-MW turbines, was the largest to date.

The Galway Wind Park will soon supersede Meenadreen, with a total of 169 MW and over 69 turbines [12]. SSE/Airtricity commissioned 22 Siemens SWT-3.0-101 D3 direct drive wind turbines, adding 64 MW of wind power capacity during their first phase in 2016.Construction also commenced on the second phase.

The average capacity factor of Irish wind farms in 2016 was 27%, less than the long-term average of approximately 31%.

3.3 Matters affecting growth and work to remove barriers

The extension of the deadline for connecting wind farms for the REFIT scheme facilitated projects which had experienced planning, grid connection, and other delays. As the replacement Renewable Electricity Support Scheme is still under development, the extension of REFIT deadlines averted a potential gap in support schemes.

In December 2016, the DCCAE published the *Code of Practice for Wind Energy Development in Ireland* [14].This publication may substantially enhance the transparency in the community benefit provision and engagement with developers regarding community concerns.

The planning processes for many wind farm projects were delayed in 2016 due to requests for judicial review of the planning appeals board's final decisions. Such reviews may have caused projects to overshoot key deadlines, but the board ultimately permitted most of the affected projects. A backlog of delayed projects may result in a peak of wind farm construction in 2017 and 2018, which could possibly lead to supply chain bottlenecks, particularly in the provision of grid connections.

The introduction of a new Integrated Single Electricity Market (ISEM) in 2018 remains a matter of concern for the wind energy sector. The government decision on how to adapt the REFIT support scheme to the new market arrangements is pending.

4.0 Impact of Wind Energy

4.1 Environmental impact

Wind energy displaced an estimated 2.19 million tons of CO_2 emissions from fossil fuel-based electricity generation in 2016. This was 10% less than in 2015 due to the low wind year. Wind energy contributed 84% of total renewable electricity output in 2016.

The All-Island Research Observatory (AIRO) at the University of Maynooth completed an Environmental Sensitivity Mapping (ESM) project in 2015, funded by the Environmental Protection Agency. This resulted in a public ESM Webtool for the strategic environmental assessment screening of infrastructure projects, including wind farms [15]. This built upon an approach pioneered by BirdWatch Ireland in 2015 for the Bird Sensitivity Map for Wind Energy Developments [16].

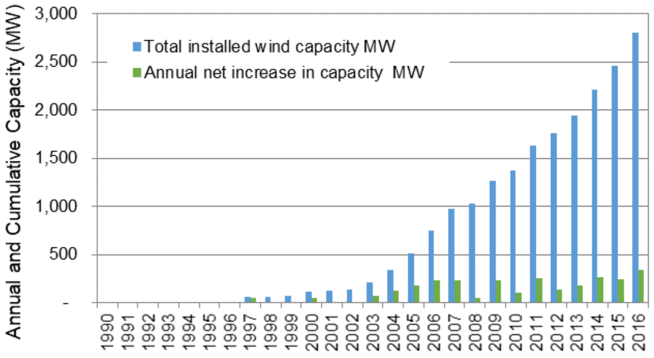

Figure 1. Cumulative and annual wind power capacity, 1990–2016

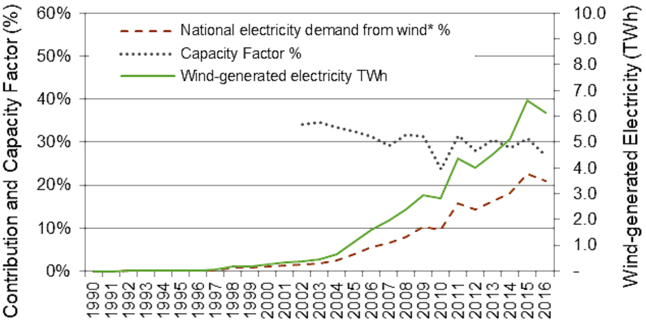

Figure 2. Wind-generated electricity, contribution to demand, and capacity factor, 1990–2016

4.2 Economic benefits

The *IEA Wind TCP 2015 Annual Report* discusses how an SEAI macroeconomic analysis of the impact of the land-based wind sector affected the Irish economy.

The Irish Wind Energy Association estimated the total employment in the wind energy sector at over 3,400 in 2016 [7]. It also found that, in order to meet Ireland's 2020 targets, land-based wind energy will need to receive a total investment of approximately 2.70 billion EUR (2.84 billion USD) between 2016 and 2020 [17, 18]. This investment would include:

- 500 million EUR (526 million USD) in construction
- 162 million EUR (170 million USD) in local advisory services
- 54 million EUR (57 million USD) in transport
- 120 million EUR (114 million USD) to landowners

4.3 Industry development

The breakdown of ownership of wind farms in Ireland was detailed in the Ireland chapters of the *IEA Wind TCP 2014 Annual Report* and the *IEA Wind TCP 2015 Annual Report*.

Table 1. Key National Statistics 2016: Ireland	
Total (net) installed wind power capacity	2,800 MW
Total offshore capacity	25.2 MW
New wind power capacity installed	345 MW
Decommissioned capacity	N/A
Total electrical energy output from wind	6.15 TWh
Wind-generated electricity as percent of national electricity demand	20.9%
Average national capacity factor	27%
Target	16% of total energy demand and 40% electricity demand from RES by 2020
National wind energy R&D budget (2015)	59,850 EUR (63,000 USD)

Ireland

EirGrid increased the maximum System Non Synchronous Penetration (SNSP) level to 55% on a permanent basis in March 2016. This increase represents the first significant move towards operating the electricity system with up to a 75% penetration of non-synchronous generation, primarily wind energy.

While Ireland does manufacture small wind turbines, there is no manufacturer of large wind turbines. Irish companies provide components, sub-systems, and services for utility scale wind turbines. The 2014 SEAI report *Ireland's Sustainable Energy Supply Chain Opportunity* provides more details on the Irish wind industry [19].

5.0 R,D&D Activities

5.1 National R,D&D priorities

The 2013 report of the Research Prioritisation Steering Group continues to guide national research priorities in Ireland. The report recommended 14 areas of opportunity, as well as underpinning technologies and infrastructure to support these priority areas, which should receive the majority of competitive public investment in STI over a five-year period to the end of 2017 [20]. 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.

An Energy Research Strategy Group was established by the Department of Communications and Natural Resources (DCENR) to develop a national strategy and roadmap for energy research in Ireland, and to ensure the implementation of this strategy. This group published its report in 2016 and national research funding allocations and priorities will be guided by its recommendations [21]. According to the group's publication, Irish research efforts for wind and solar technologies should focus on:

- Integrating power systems
- Developing smaller, cost-effective systems suitable for community-based sustainable energy initiatives
- Encouraging social acceptance of such technologies, with particular focus on models of community ownership and participation

5.2 R&D budget

Apart from funding IEA Wind TCP research Task participants by SEAI, there is no dedicated budget assigned to wind energy R&D in Ireland. General energy research budgets fund wind energy projects as required.

Currently, there is no data available on wind energy R&D expenditures in 2016. Initial 2015 statistics show that approximately 59,850 EUR (63,000 USD) was allocated to wind energy R&D projects, a decrease from 220,400 EUR (232,000 USD) in 2014. This does not consider the substantial funding allocated to R&D on integrating variable renewable energy in power system, including the EirGrid DS3 program.

The main bodies funding state-sponsored wind energy R,D&D in Ireland are as follows:

- The Sustainable Energy Authority of Ireland
- Science Foundation Ireland/Irish Research Council
- The Higher Education Authority
- Enterprise Ireland
- EirGrid
- ESB Networks
- The Commission for Energy Regulation

5.3 Research results

The Irish TSO EirGrid embarked on the Delivering a Secure, Sustainable Electricity System (DS3) program in 2016 [1]. The program aimed to operate the electricity system in a secure manner while achieving the 2020 renewable electricity targets. In October 2015, EirGrid carried out a successful system trial increasing the maximum System Non Synchronous Penetration (SNSP) level to 55%. They then decided to move to 55% on a permanent basis. This increased limit came into effect in March 2016 and represents the first significant move towards operating the electricity system with up to a 75% penetration of non-synchronous generation, primarily wind energy.

Several wind energy related R&D projects were funded by SEAI were completed in 2016 and reports detailing the results of these projects can be found on the SEAI website [22]:

- Wind Energy Research Platform and Academy, Trinity College Dublin
- Business Models for Community Wind Farms, UCC
- Local Community Ownership and Investment in RE Infrastructure, Tipperary Energy Agency
- Social and community acceptance of high voltage transmission lines and community gain messaging, NUIG

5.4 Test facilities and demonstration projects

There are currently no wind energy test or certification facilities in Ireland. No wind energy demonstration projects were executed in 2016.

5.5 Collaborative research

Participation in IEA Wind TCP has been an effective way to facilitate the growth of the Irish wind energy sector. Ireland is very active within IEA Wind TCP 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 High Turbulence Sites
- Task 28 Social Acceptance of Wind Energy Projects
- Task 33 Reliability Data: Standardizing Data Collection for Wind Turbine Reliability, Operation, and Maintenance Analyses
- Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN)

In 2016, Irish operating agent, CSS, took over leadership of Task 28 Social Acceptance of Wind Energy Projects, Trinity College Dublin developed a new Task proposal on Quiet Wind Turbine Technology, and SEAI advertised a call for tenders for new national participants in IEA Wind TCP Tasks.

SEAI places IEA Wind TCP participation at the heart of its national wind energy R,D&D program. The international collaboration helps establish best practices and stimulate national research projects in areas facilitating local deployment, initiating new task formation in areas where Ireland has research leadership and areas that present particular barriers to wind energy in Ireland.

Ireland's total installed wind power capacity grew 345 MW to a total of 2,800 MW in 2016—a new annual capacity addition record for Ireland.

6.0 Next Term

Wind farm construction activity is expected to remain high in 2017 and 2018 to complete consented projects and meet 2020 targets. Stable policies and supports have maintained investor confidence in the sector underpinning growth. Significant regulatory change affecting the wind energy sector is under way in the electricity market, specifically concerning the renewable electricity support scheme and planning regulations.

There is currently no signal as to the potential contribution of wind energy from 2020 to 2030. Ireland will require clear policy signals along with a stable policy and regulatory environment to sustain long term investment in wind energy sector.

The government has indicated that enabling host communities to invest in renewable electricity project ownership will be a core requirement of any future support scheme. Such measures have been proven to enhance social acceptance of projects. Community investment in and ownership of wind farms has not been commonplace in Ireland and wind energy sector must innovate to adapt to the new requirement.

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Opening photo: Traditional Peat Harvesting near, Bruckana Wind Farm, Co. Tipperary, Ireland (Photo credit: John Mc Cann, SEAI)

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Italy

1.0 Introduction

In 2016, new installed wind power capacity in Italy totaled 282.60 MW. Cumulative installed capacity at the end of the year reached 9,257 MW. 136 new turbines were deployed, bringing the total number of installed wind turbines to approximately 6,620. Wind-generated electricity increased from 14.6 TWh in 2015 to 17.4 TWh in 2016. This electricity production corresponds to about 5.6% of total demand.

Wind operators and associations have developed studies and deployment proposals for the repowering of old wind farms. In 2016, Italy adjusted the annual quota to 800 MW for land-based wind power capacity, which has been assigned through tender. This is a significant increase from the 500 MW quota set in 2015.

As in previous years, foreign producers supplied most of the multi-megawatt turbines installed in 2016. Few Italian industries currently engage in large wind turbine manufacturing; however, Italian industries do have a strong presence in the small wind energy systems market.

Wind energy R,D&D activities have been carried out by the following entities: universities; Ricerca sul Sistema Energetico (RES); the National Research Council (CNR); and the National Agency for New Technologies, Energy, and Sustainable Economic Development (ENEA).

2.0 National Objectives

The National Energy Strategy (SEN), issued in March 2013, outlines national objectives and policies for Italian energy systems. Four main objectives have been identified:

- Reduce energy prices
- Reach and overcome the European Commission's 2020 decarbonization targets set for Italy
- Improve safety and independence in energy supply
- Foster sustainable economic growth in energy sector

During 2016, debates began regarding the 2030 National Energy Strategy.

2.1 Targets

In 2009, Italy accepted a binding national target equaling 17% of overall annual energy consumption from renewable energy sources (RES). This is Italy's contribution to the European Union's (EU) target to have at least 20% of primary energy, electricity, heat, and transport be supplied by renewables. The 2010 Italian National Action Plan (PAN) for renewable energy distributed this overall national target across several sectors.

The electrical sector set an RES target of 26.39%, which equates to 43.8 GW of RES capacity and 98.9 TWh/yr RES production by 2020. Wind-based electrical energy accepted a 12.68 GW MW (12.0 GW land-based and 0.680 GW offshore) target for installed capacity, and a 20 TWh/yr (18 TWh/yr land-based and 2 TWh/yr offshore) target for electricity production.

2.2 Policies supporting development

The main issue of the present incentive mechanism supporting renewables is fixed energy purchase prices for RES-E plants below a capacity threshold, depending on technology and size (no lower than 5 MW). Larger plants receive special energy purchase prices through calls for tenders (until the annual quota is reached), which are granted over the average conventional lifetime of plants (20–25 years).

The 2016 quota for wind power capacity was 800 MW land-based (compared to 500 MW in 2015) and 30 MW offshore.

Since the introduction of tariffs and annual quotas in 2012, installations have significantly declined (from approximately 1,000 MW/yr in 2008-2012 to about 300 MW/yr in 2013–2016). The incentive tariff for wind power plants with a size of 20–200 kW was also significantly lower than in 2015.

3.0 Implementation and Deployment

3.1 Progress

According to the National Wind Energy Association (ANEV), Italy installed a new net wind power capacity of 282.60 MW in 2016. Cumulative installed capacity at the end of 2016 reached 9.26 GW, including decommissioning and repowering. All of Italy's wind power capacity is land-based. If annual growth were constant in the coming years, the 2020 national land-based target of 12,000 MW installed wind power capacity could not be achieved (Figure 1).

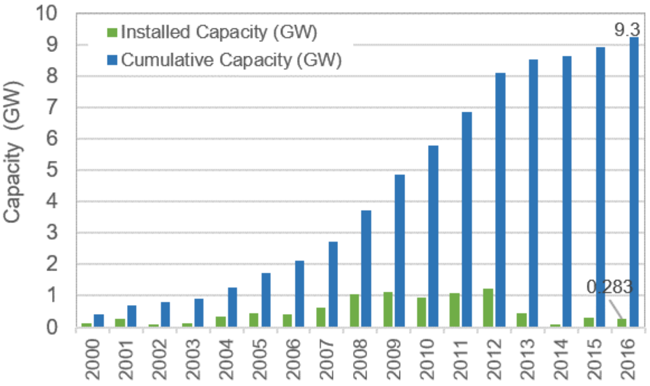

Figure 1. Annual and cumulative capacity in Italy (2000-2016)

TERNA, the national TSO, provisionally estimated that wind-generated electricity in 2016 totaled 17.4 TWh—5.6% of Italy's total electricity demand (total consumption plus grid losses) [1]. The trend of Italian wind energy generation is shown in Figure 2. Most of the cumulative installations are in the southern regions of Italy according to wind resource availability (Figure 3). In 2016, wind power installations took place mainly in the Apulia, Basilicata, Campania, and Sicily regions.

3.2 Operational details

In 2016, 31 wind farms were grid-connected. Approximately one-third of the farms have a capacity greater than 10 MW (maximum 60 MW), one-third have a capacity between 1–10 MW, and one-third have a capacity lower than 1 MW (single wind turbines). Also in 2016, Italy deployed 136 new turbines, reaching a total of nearly 6,620 installed wind turbines. The average wind turbine size installed during the year was 2 MW, while the maximum size was 3.5 MW (Vestas V126). The average size of all wind turbines installed in Italy is 1.4 MW.

The average capital cost to install wind farms between 200 kW to 60 MW is approximately 1,500 EUR/kW (1,580 USD/kW). For wind farms larger than 5 MW, the average capital cost of installation is approximately 1,340 EUR/kW (1,411 USD/kW).

3.3 Matters affecting growth and work to remove barriers

Winners of the tender for large land-based wind farms have two years to complete their installation and grid-connection. Although there are a number of winners that overcome the quota each year, new capacity has been significantly below the annual quota since 2013. The above mentioned increase of the land-based annual quota was set in 2016 to foster higher growth in the coming years.

The reduced incentive tariff for small wind turbines will probably negatively affect the growth of these installations in the next years. The 2016 annual quota for offshore wind has been reduced to 30 MW.

The high-density population, complex terrain, widespread tourism, and landscape impact could affect the acceptance and growth of wind power in Italy.

4.0 Impact of Wind Energy

4.1 Environmental impact

According to the Italian National Institute for Environmental Protection and Research (ISPRA), substituting one kWh produced by fossil fuels with one produced by renewable sources avoids the 554.6 g in CO_2 emissions [2]. In 2016, wind-generated electricity avoided 9.7 million tons of CO_2 emissions in Italy.

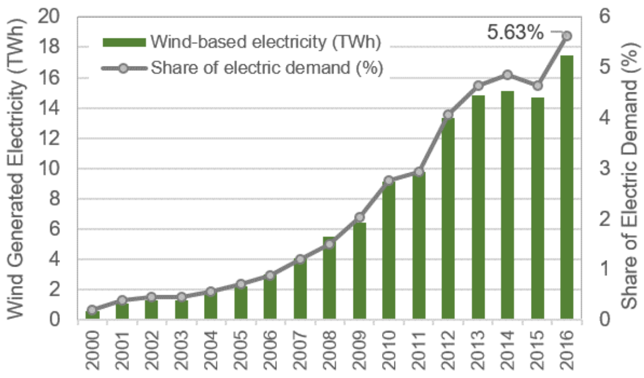

Figure 2. Trends of Italian wind energy generation (2000–2016)

Wind-generated electricity in Italy increased from 14.6 TWh to 17.4 TWh in 2016, meeting about 5.6% of total demand.

4.2 Economic benefits

In 2016, the economic impact of wind energy in Italy was an estimated 3.7 billion EUR (3.9 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.

New installations, including both preliminary (design, development) and executive (construction, equipping, grid-connection) activities, contributed an estimated 424 million EUR (446 million USD). O&M of the online plants contributed approximately 349 million EUR (367 million USD). Finally, wind energy production and commercialization's impact was valued at 2.793 billion EUR (2.941 billion USD).

ANEV reports that the number of jobs in the wind energy sector was stable through 2016 and totaled 26,000 units (including direct and indirect involvement).

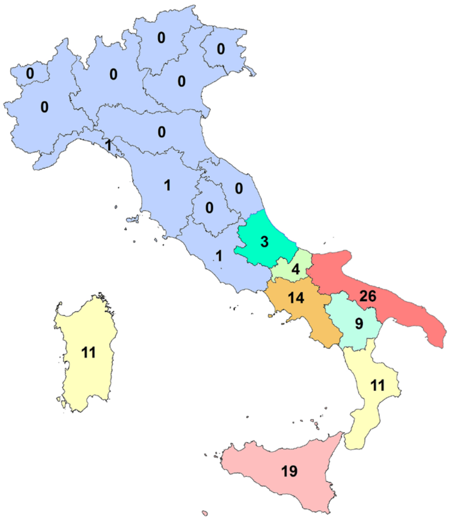

Figure 3. Share of the distribution of the cumulate wind power capacity as of 31 December 2016, in percentages

Table 1. Key National Statistics 2016: Italy	
Total (net) installed wind power capacity	9,260 MW
Total offshore capacity	0 MW
New wind power capacity installed	280 MW
Decommissioned capacity	10 MW
Total electrical energy output from wind	17.4 TWh
Wind-generated electricity as percent of national electricity demand	5.6%
Average national capacity factor	19.6%
Target	12,000 MW land-based; 680 MW offshore by 2020
National wind energy R&D budget	N/A

4.3 Industry development

Concerning the owners/operators of the overall wind projects, the situation in Italy is rather dynamic. In recent years, there has been a non-negligible trade of wind projects [3]. There are four big players in the Italian wind energy market, whose shares exceed than 5%: Erg Renew, Enel Green Power, Fri-el, and E2i Energie Speciali. Approximately 20 players have shares near to or greater than 1%. Several other small players account for the remaining half of the market (Figure 4).

Foreign manufacturers prevail in the Italian large-sized wind turbine market. The shares of the new 2016 wind capacity are:

- 41.1% by Vestas (Denmark)
- 18.8% by Gamesa (Spain)
- 12.6% by Enercon (Germany)
- 10% by Nordex (Germany)
- 9.1% by Senvion (Germany)

Leitwind is the only Italian manufacturer for the large-sized wind turbine sector. Vestas has two production facilities in Taranto. In contrast to the large wind-turbine sector, Italian firms have a significant presence in the small-sized wind turbine market (up to 200 kW).

5.0 R,D&D Activities

5.1 National R,D&D priorities

There is no coordination of wind energy R,D&D activities at national level; however, many organizations are involved in wind energy research.

5.2 R&D budget

Each research organization or university sets its own budget for wind energy R&D. Therefore, it's quite difficult to give a representative value for the whole budget or to evaluate trends.

5.3 Research results

The POLI-Wind group has been working on wind turbine aero-servo-elasticity, blade design, load mitigation, and advanced control laws at the Aerospace Department of Politecnico di Milano. POLI-Wind is a member of two ongoing projects funded by the Seventh EU Framework Programme (FP7): INNWIND and AVATAR. These projects study advanced technologies for very large wind turbines in the 10–20 MW range.

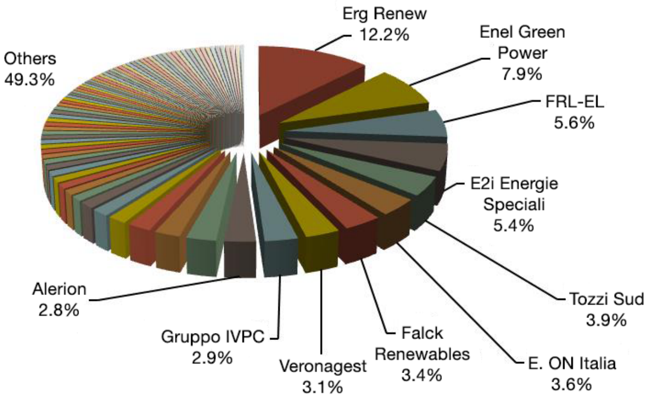

Figure 4. Market share of the wind energy producers at the end of 2016

POLI-Wind has also developed a wind tunnel testing facility, which includes actively controlled and aero-elastically scaled wind turbine models for the simulation of wind farms and the study of wake interactions. Thanks to this expertise, Politecnico di Milano became a member of the Horizon 2020 EU-program CL-Windcon in 2016. CL-Windcon will address control algorithms at the wind farm level. Finally, the Department of Mechanical Engineering has a partnership in another Horizon 2020 project, LIFES50+, on floating substructures for 10-MW wind turbines.

The Aircraft Design and AeroFlightDynamics Group (ADAG) of University of Naples "Federico II," in cooperation with Seapower Scarl, has been involved in design, development, installation, and field testing of small and medium vertical axis wind turbines (VAWT) and horizontal axis wind turbines (HAWT), according to IEC-61400-1 standards, for more than 25 years. Their research focuses on blade design, airfoil wind tunnel testing, load determination through aero-elastic analysis, aerodynamic and load measurements from field testing, windmill cost optimization for low wind speed sites and optimization of composite manufacturing techniques to minimize the cost of blades.

The University of Florence's Interuniversity Center for Aerodynamics of Construction and Wind Engineering (CRIACIV) developed an accurate simulation tools for large fixed-bottom and floating offshore wind turbines. CRIACIV collaborated with CNR-INSEAN and other national and international research institutions. Their recent findings are about the implications nonlinear wave models have on the extreme and fatigue loads of offshore wind turbines. CRIACIV is a participant in Horizon 2020 projects such as MARINET2 and MSCA-ITN AEOLUS4FUTURE, as well as the COST Action TU1304 WINERCOST.

The Wind Energy Group of the Department of Industrial Engineering at the University of Padova worked on the aero-structural optimization of both HAWT and VAWT. Much of their work focused on coupling BEM and FEM methods for optimization and examining the economic aspects of energy production. The group investigated the response of a HAWT under gust conditions using a CFD-based model. They also developed an optimization environment for VAWT analysis by integrating open source codes and in-house functions.

The Department of Mechanical and Aerospace Engineering at the Politecnico di Torino developed a suite of numerical design and modeling tools to study the dynamic behavior of offshore floating hybrid platforms. The Department of Energy has been working on optimal power sharing between photovoltaic generators, wind turbines, storage, and grids to feed tertiary sector users.

The Department of Mechanical and Aerospace Engineering at the Sapienza University of Rome worked on turbine aerodynamic and structural design. This department has been the headquarters of the OWEMES association (www.owemes.org) since 2013. OWEMES is devoted to the promotion of offshore wind and ocean energy sources and cooperates with several universities and research institutes in Italy.

The University of Trento is active in small turbine design and testing. The university conducts their tests on its own experimental 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.

Research on the Energy System (RSE S.p.A.) is a joint stock company developing research activities in the electro-energy sector. Their activities examine wind energy resource and production forecasting, grid integration, resource assessment through measures and models, and an empowered wind and renewable atlas.

CNR activity in wind energy now involves two institutes and is in the frame of national and EU FP7 projects. Two institutes, Institute of Atmospheric Sciences and Climate (ISAC) and the Marine Technology Research Institute (INSEAN), focus on wind condition, aerodynamics, infrastructures, and offshore technologies. CNR-INSEAN hosts a wave tank and circulating water channel. These world-class facilities allow researchers to test model-scale offshore wind turbines installed on a floating platform in a controlled environment. These tests are also in the frame of EU MARINET projects. Under the IRPWIND project, CNR-ISAC manages the Mobility programme, an innovative schema to facilitate cooperation of experienced researcher among EERA JPWIND members.

The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) has used its wind tunnel facility to test anemometers and small wind turbines. ENEA is also involved in developing non-destructive evaluation methods on materials and components, based on X-ray high resolution computed tomography.

KiteGen research and Sequoia Automation companies are studying kite-based wind generation with a project of 3-MW kite wind generator.

5.4 Collaborative research

RSE has long been the Italian participant in IEA Wind TCP Task 11 Base Technology Information Exchange. In 2014, RSE and the Department of Mechanical Engineering of Polytechnic of Milan also joined the extension of Task 30 Offshore Code Comparison Collaboration, Continued, with Correlation (OC5). TERNA participates in Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power.

CNR is a full participant in EERA's joint program on wind energy, while Polytechnic of Milan and RSE are associated participants.

6.0 The Next Term

Repowering older wind farms could be an interesting option for the future of wind energy, as old generation wind turbines are installed in many windy sites. Wind operators and associations have developed proposals and studies in this direction.

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Opening photo: Melfi Wind Farm (Photo credit: Finpower Wind)

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Japan

1.0 Introduction

In 2016, the total installed wind power capacity in Japan reached 3,234 MW, including 59.6 MW of offshore capacity. The annual net capacity increase was 195 MW. Total wind-generated electricity during 2016 was about 5.3 TWh, which corresponds to 0.55% of the national electricity demand (920.1 TWh).

The signs of recovery from the strict Environmental Impact Assessment (EIA) Law are becoming ever more apparent. More than 11 GW of new wind farm projects are still suspended by EIA processes. Nearly 88% of the projects in planning are located in the Hokkaido and Tohoku regions. These regions have plenty of wind resources, but low population in these areas creates low electric demand and grid connection problems.

2.0 National Objectives

2.1 Targets

Following the publication of the Fourth Strategic Energy Plan, the Ministry of Economy, Trade and Industry (METI) issued the "Long-term Energy Supply and Demand Outlook," including a draft for the power source mix in 2030 [1].

The projected share of wind energy in the 2030 power source mix is 1.7%, which corresponds to 10 GW of capacity including 0.82 GW offshore wind power. This means only 7 GW of new installation are required to meet the target in the next 14 years.

2.2 Policies supporting development

Japan adopted the FIT scheme to support the development of renewable energies, including wind power, in July 2012. The country's former incentive programs were investment subsidies and renewable portfolio standards.

The current tariffs are 22 JPY/kWh (0.18 EUR/kWh; 0.19 USD/kWh) for wind power greater than or equal to 20 kW of capacity and 55 JPY/kWh (0.45 EUR/kWh; 0.47 USD/kWh) for wind power less than 20 kW of capacity. The premium tariff for offshore wind is 36 JPY/kWh (0.29 EUR/kWh; 0.31 USD/kWh). The above tariffs do not include the 8% consumption tax. The duration of the FIT is 20 years for wind, including small wind and offshore wind.

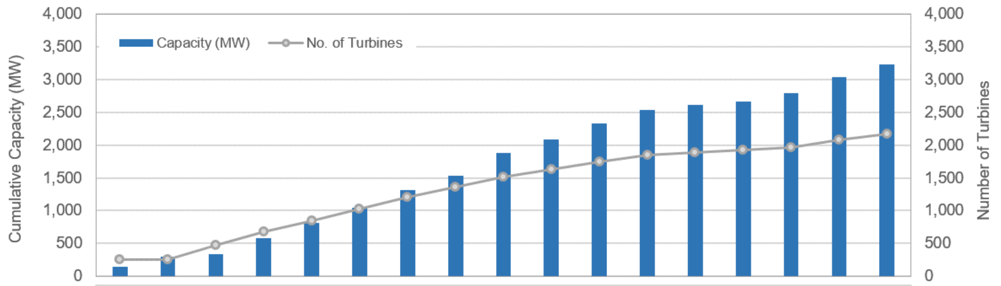
The tariff will be re-assessed every year based on the latest market experience in Japan. METI drafted a modified tariff for wind and solar power in 2016, which would reduce the tariff for land-based wind power each year until FY 2019. According to the draft, the FIT for land-based wind would be reduced 1 JPY/kWh (0.0081 EUR/kWh; 0.0086 USD/kWh) every fiscal year, from 22 JPY/kWh (0.18 EUR/kWh; 0.19 USD/kWh) in FY 2016 to 19 JPY/kWh (0.15 EUR/kWh; 0.16 USD/kWh) in FY 2019. The tariff for offshore wind would maintain a constant rate of 36 JPY/kWh (0.29 EUR/kWh; 0.31 USD/kWh).

Projects that are delayed by grid issues receive special remedial measures. Japan offers a new tariff for repowering wind power, which is 3 JPY/kWh (0.024 EUR/kWh; 0.026 USD/kWh) lower than the tariff for large wind power. METI finalized the new tariff for FY 2017 after reflecting upon public hearing results in March 2017.

3.0 Implementation and Deployment

3.1 Progress

Although wind farm projects continue to feel the influence of the 2012 EIA Law, the wind energy sector has begun to see signs of recovery (Figure 1). The EIA Law requires developers of wind power plants with more than 10 MW of capacity to implement an environmental impact assessment of the project. This process can take about four years.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
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	3,234
No. of Turbines	251	247	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	2,175

Figure 1. Total installed wind power capacity and number of turbines in Japan

3.2 Operational details

Japan installed a total of 195 MW in 2016. The annual net increase in capacity is approximately 20% smaller than 2015, when 244 MW were installed. Cumulative wind power capacity reached 3,234 MW across 2,077 turbines at the end of the year. The total electrical energy output from wind during 2016 was approximately 5.3 TWh—0.55% of the national electricity demand. Several large wind farms have finished the long EIA process and started operation (Figure 2).

Japan's operational offshore wind power capacity reached 59.6 MW in 2016. In the Fukushima FORWARD project, one 7-MW offshore wind turbine with a floating foundation began operation in April 2016, which was originally installed in July 2015. Fukushima FORWARD also installed a 5-MW wind turbine on the advanced spar type floater manufactured by Japan Marine United Corporation (JMU). The turbine started official operation in March 2017.

In April 2016, a Hitachi 2-MW downwind turbine was reconnected to the grid line and began commercial operation (Figure 3). This turbine was originally installed in the Ministry of Environment (MOE) demonstration research area approximately 1 km offshore from Kabashima Island in Nagasaki Prefecture on a hybrid (steel and concrete) spar type floater in 2013. It was moved to about 10 km southwest to the neighboring larger island Fukuejima and began commercial operation in April 2016. After reconnecting to the grid, this turbine became the first offshore wind project to receive the premium tariff for offshore wind (36 JPY/kWh; 0.29 EUR/kWh; 0.31 USD/kWh) in Japan.

3.3 Matters affecting growth and work to remove barriers

FITs will now be approved in the middle of the EIA process—two to three years prior to a project's beginning. This should significantly improve predictions of wind power profitability.

Unlimited curtailment without compensation is an obstacle to wind power development in Japan. Formerly, electric power companies were obliged to pay compensation to the wind generation companies when curtailment due to grid issues exceeded 30 days. Now, electric power companies can curtail renewable energy when the rate of renewable energy reaches a certain ratio. This ratio is estimated at less than 30% in Hokkaido and Tohoku, and at less than 10% in Kyusyu and Shikoku.

Priority access to the grid for renewable energy has not been realized in Japan. The mismatch between the location of wind resources and electricity demand causes grid connection problems. For example, the northern areas (Hokkaido and Tohoku) have good wind resources, but low population rates limit the grid infrastructure. Tohoku Electric Power Co., Inc. announced in 2016 that they would reject new requests for grid connection in three of Japan's northern prefectures: Akita, Aomori, and Iwate. Hokkaido Electric Power Co., Inc. is required to install large-scale batteries for new wind farm projects to stabilize the fluctuation of output to wind power developers from April 2016.

4.0 Impact of Wind Energy

4.1 Industry development

Three Japanese wind turbine manufacturers produce turbines larger than 2 MW: Mitsubishi Heavy Industries (MHI), Japan Steel Works (JSW), and Hitachi. MHI licensed a 2.5-MW wind turbine (MWT 100A/2.5) to Hitachi for domestic manufacturing, sales and operation and maintenance business beginning in December 2015.

Japan's wind energy sector has begun to recover from the 2012 EIA Law; in 2016, the total installed wind power capacity in Japan reached 3,234 MW, including 59.6 MW of offshore capacity.

Hitachi developed a 5.2-MW downwind turbine, the HTW5.2-136 in 2016. It is a large-diameter version of a previous model, the HTW5.0-126. The new turbine has made it possible to increase output in low wind speed regions that have an annual average wind speed below 7.5 m/s by increasing the rotor diameter to 136 m, thereby enlarging the wind-swept area by 15%. Hitachi intends to market the HTW5.2-136 for low wind speed regions along the coasts of Honshu, the main island of Japan.

Hitachi also plans to market another turbine, the HTW5.2-127, for strong wind sites. These sites would include the coasts of Hokkaido, the northern part of the Tohoku region on Honshu, and southern Kyushu. Hitachi has optimized the setup and control programs of the HTW5.2-127, increasing its rated power from that of the previous model.

In 2016, Penta-Ocean Construction Co., Ltd. announced they would build their own jack-up ship for offshore wind turbine installation or marine civil engineering works.

5.0 R,D&D Activities

5.1 National R,D&D Priorities

The main national R&D programs by METI, the New Energy and Industrial Technology Development Organization (NEDO), and the MOE are as follows:

NEDO Research and Development of Offshore Wind Power Generation Technology (FY 2008 to FY 2017):

- *Demonstration Research of Offshore Wind Power Generation System* (FY 2009–2016) and *Demonstration Research of Offshore Wind Measurement System* (FY 2010–2016): In these projects, offshore wind turbines and measurement platforms were installed at test sites in Choshi, Chiba Prefecture and Kitakyusyu, Fukuoka Prefecture. The main purpose of these offshore R&D projects is to establish design methodologies against Japan's severe offshore

Table 1. Key National Statistics 2016: Japan

Total (net) installed wind power capacity	3,234 MW
Total offshore capacity	59.6 MW
New wind power capacity installed	195 MW
Decommissioned capacity	N/A
Total electrical energy output from wind	5.3 TWh
Wind-generated electricity as percent of national electricity demand	0.55%
Average national capacity factor	19%
Target	10 GW wind power capacity by 2030
National wind energy R&D budget	8.4 billion JPY (68 million EUR; 72 million USD) in FY 2016

Figure 2. The JRE Nakakyushu-Onitayama Wind Farm in Miyazaki prefecture (Hitachi 2-MW 8 turbines with total capacity of 16 MW) began operation in September 2016 (Source: Japan Renewable Energy Corporation, JRE)

conditions, such as typhoons, and to demonstrate the reliability and the commercial feasibility of offshore wind turbine generation in Japan.

- *Development of Environmental Impact Assessment Method (FY 2009–2016)*: In September 2015, NEDO published two documents on its homepage: “The Basic Document on Environmental Impact Assessments of Bottom Mounted Type Offshore Wind Power Generation (First Edition)” and “The Guide Book to Introduce Offshore Wind Power Generation (First Edition).” These documents serve as a reference for wind power developers. The final edition of the basic document and the guide book will be published in 2017.
- *Research on Next-Generation floating Offshore Wind Power Generation System (FY 2014–2017)*: To reduce the costs associated with floating offshore wind power generation systems, an empirical study of has been conducted in relatively shallow areas of the sea. This study determines the potential for floating offshore wind power capacity at a water depth of 50–100 m.
- *Development of Floating Offshore Wind Measurement System (FY 2013–2015)*: NEDO developed a wind profile observation system, consisting of Doppler LIDAR with inclination compensation as well as measurements of the motion of the floating unit and waves. The project contractor compares observed data by the LIDAR on the floating unit and the tower on the breakwater and evaluates and demonstrates the reliability of the floating LIDAR system.
- *Offshore Wind Map (FY 2015–2017)*: NEDO developed a 500-m grid resolution offshore wind database within 20 km of the Japanese coastlines, which became publicly accessible in March 2017. This database utilizes the mesoscale meteorological model Weather Research and Forecasting (WRF). The simulation target accuracy is an annual bias of less than ±5% in wind speed at a hub height of 80 m. In addition to coastal winds, researchers also collected data on open-ocean winds using satellite observations. Social and environmental information data, such as significant wave height, fishing rights, shipping routes, water depth, and seabed property, which are associated with offshore wind development, are integrally stored in the database.

Figure 3. Hitachi 2-MW floating offshore wind turbine at Fukuejima in the Nagasaki prefecture (Photo credit: Ueda, Y., JWPA)

METI Floating Offshore Wind Farm Demonstration Project (Fukushima FORWARD PJ) (FY 2011 to FY 2016): For this project, METI installed several offshore wind turbines with various types of floaters in the Pacific Ocean, more than 20 km offshore of Fukushima prefecture.

In 2013, 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 was installed and began operation. In 2015, a MHI 7-MW wind turbine with a three-column, semisubmersible floater was anchored to the demonstration site and began commissioning. In 2016, A Hitachi 5-MW downwind turbine with an advanced spar type floater manufactured by the Japan Marine United Corporation (JMU) was installed. It began official operations in March 2017 (opening photo).

NEDO Advanced Practical Research and Development of Wind Power Generation: R&D on advanced components and maintenance technologies applicable to next-generation very large wind turbines began in FY 2013. The aim of this national project is to further reduce the cost of wind energy. Research includes:

- *Advanced Practical Development of Wind Turbine Component (FY 2013–2017)*
- *R&D of Smart Maintenance Technologies (FY 2013–2017)*
- *Commonization and Demonstration Research of Small Wind Turbine Component (FY 2014–2016*)

5.2 Collaborative research

Japan withdrew from IEA Wind TCP Task 29 Mexnext: Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models, but will join Task 26 Cost of Wind Energy in 2017. Japan also participates in:

- Task 11 Base Technology Information Exchange
- Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power
- Task 27 Development and Deployment of Small Wind Turbine Labels for Consumers (2008–2011) and Small Wind Turbines in High Turbulence Sites (2012–2016)
- Task 28 Social Acceptance of Wind Energy Projects
- 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.

Japan also participates in many maintenance teams, project teams, and working groups in IEC TC 88.

6.0 Next Term

More than 11 GW of new wind farm projects are still suspended by EIA processes. Most projects in the later stages of the EIA process have grid connection permits and feed-in tariff (FIT) approval at 22 JPY/kWh (0.18 EUR/kWh; 0.19 USD/kWh). These projects will start operation within four years. Other planning projects still need permission to connect to the grid; therefore, their operation dates remain uncertain.

References:

Opening photo: A 5-MW wind turbine manufactured for the Fukushima FORWARD project installed on the advanced spar type floater manufactured by the Japan Marine United Corporation (Source: Fukushima Offshore Wind Consortium)

[1] www.meti.go.jp/english/press/2015/0716_01.html

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Republic of Korea

1.0 Introduction

The Republic of Korea installed approximately 115 MW of wind power capacity in 2016. Installations in 2016 increased by 14% over 2015, with an estimated cumulative total of 967 MW. Domestic manufacturers supplied more than 70% of the installed wind turbines in 2016.

In 2012, Korea enacted a Renewable Portfolio Standard (RPS) to support renewable energy. The required rate of RPS in 2016 was 3.5%, which was achieved in the fifth year. Aggressive investments by the government and the RPS are expected to accelerate the growth of wind energy in Korea.

A nine-year plan for a 2.5-GW offshore wind farm on the country's west coast was announced in 2010; the plan has been postponed for several years, but the first stage of the project is in progress—construction of 60-MW wind farms.

Since 2009, the Korean government has supported local component manufacturers within the supply chain and increased the R&D budget to develop core technologies for wind power.

2.0 National Objectives

Korea is focusing on wind energy to replace fossil fuels and nuclear energy. The government continues to increase the R&D budget to support wind turbine and component manufacturers as they develop their own technologies and products.

2.1 Targets

Korea set a target to replace 9.7% of the nation's total energy consumption with renewable energy by 2030. Currently, a significant portion of the country's renewable energy production is biomass. The government aims to reduce the dependency on the biomass by focusing on solar PV and wind energy (Table 1). A secondary goal is to increase wind energy technology and become an industry leader.

2.2 Policies supporting development

The government subsidies for installing New and Renewable Energy (NRE) facilities increase deployment and unburden the end user. Special focus has been placed on school buildings, warehouses, industrial complexes, highway facilities, factories, and electric power plants. Up to 50% of the wind power installation cost is compensated by the government, especially for demonstration projects and for private use.

Green energy requirements apply to any new construction, expansion, or remodel of public buildings with a floor area exceeding 1,000 m^2. Here public buildings are required to fulfill more than 10% of their total energy use with renewable energy.

The Feed-in Tariff (FIT) for wind energy had a flat rate of 0.1 USD/kWh (0.095 EUR/kWh) for 15 years. Recently, however, the standard price is adjusted annually, reflecting the change of the NRE market and economic feasibility of NRE. Korean wind farms installed before 2011 received FITs, and wind farms constructed since 2012 are supported with RPS.

With the RPS, major electric power suppliers are required to use renewable energy (including wind power) to provide a certain amount of their electric power. The RPS was enacted in 2012 with a target rate of 3.5% of electric power and is applied to electric power suppliers providing more than 500 MW. The target rate will increase to 10% in 2024. This regulation compels power suppliers to invest in wind energy deployment (Table 2). New installation has doubled since the RPS was implemented in 2012.

Table 1. National Targets for Renewable Energy Resources (% of Renewables)

Year	Target Share of Renewables (%)							
	Biomass	Bioenergy	Geothermal	Hydro	Ocean	Solar PV	Solar Thermal	***Wind***
2020	47.3	17.6	2.5	6.3	2.4	11.1	1.4	***11.3***
2025	38.8	19.0	4.4	4.1	1.6	12.9	3.7	***15.6***
2035	29.2	18.0	8.5	2.9	1.3	14.1	7.9	***18.2***

Table 2. Comparison of the RPS Effects by New Installation Record

Year	2009	2010	2011	2012	2013	2014	2015
New installation (MW)	47.3	30.9	26.6	54.5	89.6	58.6	207

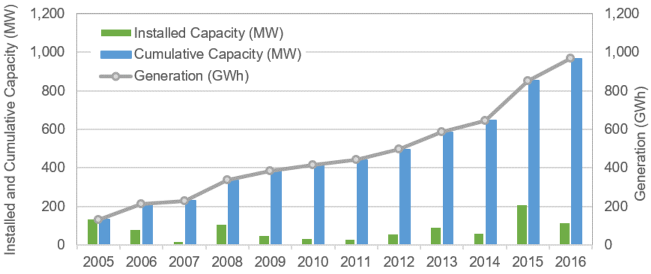

Figure 1. Installed and cumulative wind power capacity in the Republic of Korea (2005-2016)

The RPS weight factors vary: land-based wind farms (1.0), offshore wind farms over 5 km from shore (1.5), and under 5 km from the shore (2.0). To stabilize the price of the renewable energy, the summation of Renewable Energy Certificates (REC) and System Marginal Prices (SMP) can be fixed and contracted for 20 years. In 2016, the fifth year of RPS, the 3.5% annual target was achieved. Due to complaints about the pending RPS target increase, the government moved the 10% target year from 2022 to 2024.

Additional loan and tax deductions, local government NRE deployment programs, and other national incentive programs are also available.

3.0 Implementation and Deployment

3.1 Progress

New installations have gradually increased due to relaxed site development restrictions. By 2016, total wind power installations >200 kW totaled an estimated 967 MW—a 14% growth over the previous year (Figure 1). In 2014, the Korean government relaxed the restrictions for land-based wind turbine site development and simplified the approval process. By 2016, new wind power installation totaled approximately 115 MW. New installations are expected to reach 300 MW in 2017, bringing the accumulated wind power capacity over 1 GW.

There are two major elements escalating the growth of wind energy. The first is the construction of a 2.5-GW offshore wind farm in the west sea. According to the original roadmap proposed by the government, the farm would be constructed in three stages over nine years, beginning in 2011.

In the first four-year period, 60 MW of wind power would be installed as a demonstration. In the following two years, 400 MW would be installed for operational experience and commercial purposes. Finally, a 2-GW wind farm would be constructed with 5-MW wind turbines for commercial purposes. The project has an estimated cost of 7.5 billion USD (7.1 billion EUR). However, the construction has been delayed for several reasons and the government has modified the construction plan (Table 3).

Table 3. Construction Plan for a 2.5-GW Offshore Wind Farm

	Demonstration	Standardization	Deployment
Objective	Test set up, track record, and site design	Operational experience, validation of commercial operation	Cost effectiveness per GW, site development and commercial operation
Wind power	60 MW	400 MW	2,000 MW
Schedule	2011–2018 (7 years)	2019–2020 (2 years)	2021–2023 (3 years)

> **The Republic of Korea's total installed wind power capacity reached approximately 967 MW in 2016—14% growth over the previous year.**

3.2 Operational details

In 2015, 207 MW of wind power capacity was installed in Korea. Half of these turbines (ten 3-MW units, 15 2-MW units, and 18 3.3-MW units) were supplied by foreign manufacturers Alstom, Siemens, and Vestas, respectively.

More than 50% of the newly installed wind turbines were supplied by domestic manufactures: Doosan, Unison, and Hanjin also supplied turbines. However, most ship building and heavy industry companies have closed their businesses due to slow technology development and the global economy crisis. Among the domestic turbine suppliers, only Doosan heavy industry, Unison, and Hanjin continue to manufacture wind turbines.

Newly installed wind turbines, especially those supplied by the domestic manufacturers, do not currently serve commercial purposes. Instead, these turbines operate to perform system checks and accumulate operational track records. There is not much of an electric output record, so it is still difficult to estimate the real cost of wind energy.

3.3 Matters affecting growth and work to remove barriers

Because most of Korea's high mountains are preserved areas, it was difficult for new wind farms to get approval to begin construction. The central government adjusted the environmental protection regulations, which simplified the wind farm approval process. As a result, Korea installed 207 MW of new wind power in 2015 and 115 MW in 2016.

4.0 Impact of Wind Energy

4.1 Economic benefits

The impact of the wind energy industry is very limited in the Korean economy. In 2015, net production sales equaled 1.214 billion USD

Table 4. Key National Statistics 2016: Korea

Total (net) installed wind power capacity	***967 MW***
Total offshore capacity	0 MW
New wind power capacity installed	***115 MW***
Decommissioned capacity	---
Total electrical energy output from wind	1.342 TWh (2015)
Wind-generated electricity as percent of national electricity demand	0.24% (2015)
Average national capacity factor	---
Target	2% wind energy by 2035
National wind energy R&D budget	---
Bold italic indicates estimates	

Republic of Korea

(1.153 billion EUR) and the number of employees working in the wind energy industry was approximately 2,369.

The cost of Korean wind turbines and components are high and not competitive for foreign suppliers. However, companies continue to develop wind energy technology. Doosan is developing a new turbine for the offshore wind farm. Unison designed a wind turbine suitable for the Korean atmosphere, which is characterized for low wind speeds. Unison also developed a 2.5-MW turbine with two tower heights and longer blades.

Korea's net sales wind energy sector came from generation systems, towers, and components. Component sales increased from 30% to 44% in 2015; turbine system sales decreased from 31% to 18.5% (Table 5). The number of employees working in the wind energy industry was estimated at 1,988 in 2013, increased to 2,424 in 2014, and slightly decreased to 2,369 in 2015. The number of manufacturers increased slightly in 2015 (Table 6).

The wind energy industry in Korea is currently being restructured. Many casting component companies have changed their business because of the severe competition with the Chinese companies. Employment among these companies has steadily

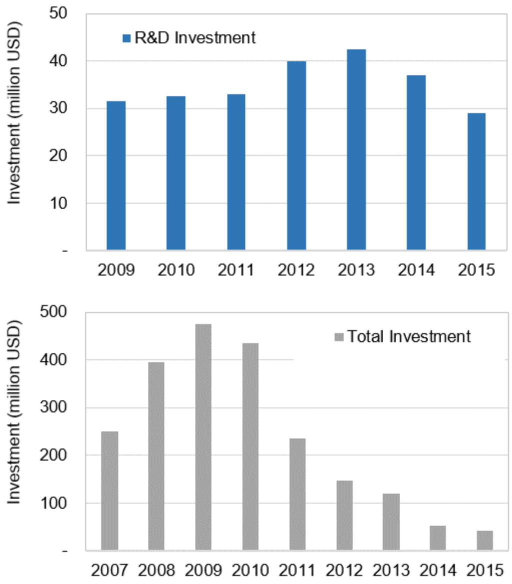

Figure 2. a) R&D investment in wind energy industry by the Korean government and b) total investment in the wind energy industry

Table 5. Total Sales in the Wind Energy Industry in Korea									
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015
Total Sales									
Total Sales (million USD; million EUR)	526; 500	1,099; 1,044	912; 866	826; 785	857; 814	1,085; 1,031	852; 809	943; 896	1,215; 1,154
Growth Rate (%)	-	108	-18	-10	3	26	-22	10	29
Employment									
Turbine System	236	312	727	957	1,021	1,000	1,112	1,159	899
Casting Components	925	1,193	1,163	1,032	810	431	347	396	461
Other	273	355	442	565	625	599	529	869	1,009
Total Employment	**1,434**	**1,860**	**2,332**	**2,554**	**2,456**	**2,030**	**1,988**	**2,424**	**2,369**

Table 6. Number of Companies in the Korean Wind Energy Industry						
	Korean Wind Energy Companies					
Year	Generating Systems	Blades	Towers	Inverters	Components	Total
2014	20	4	5	1	7	34
2015	20	5	5	1	10	37
Growth Rate (%)	0.0	25.0	0.0	0.0	42.9	8.8

decreased, from 1,163 in 2009 to 461 in 2015. However, the number of employees working on turbine systems has increased from 236 in 2007 to 899 in 2015.

5.0 R,D&D Activities

5.1 National R,D&D priorities

Government investment in wind energy R&D has decreased since 2013, but the government invested 30 million USD (28.5 million EUR) in 2015 to escalate the wind energy industry (Figure 2a). Total investment for the wind energy industry peaked in 2009 and has continued to fall ever since (Figure 2b). However, new installation increased drastically in 2015 and 2016, which should provoke new investment in wind energy.

6.0 Next Term

Poor wind conditions, minimal available land, and strong government opposition have damaged the optimistic vision of wind energy in Korea. Major turbine developers have closed their businesses due to slow technology development and severe competition with Chinese companies.

However, RPS provides motivation for renewable energy investment. The 2.5-GW offshore wind farm will resume construction in 2017, which is expected to contribute 300 MW of new installation. These factors will support the Korean wind energy industry for the near future.

References:

Opening photo: Gasado Wind and Solar PV Farm (Courtesy of Korea Electric Power Co.)

Authors: Cheolwan Kim, Korea Aerospace Research Institute; and Sang-geun Yu, Korea Energy Management Corporation, Korea.

México

1.0 Introduction

México's wholesale electricity market began operation in 2016. Due to the new policies and legal framework of the country's energy reform, the Mexican wind market has begun to evolve. In 2016, México added 454 MW of new wind power to the country's electricity grid, bringing the total capacity to 3,527 MW. This represents about 5% of total generation capacity [1].

México's wind industry aims to install 12 GW by the end of 2020, and 15 GW by the end of 2022. In México, auction mechanisms allow the development of wind power at competitive prices.

The newly established Mexican Wind Energy Innovation Center (CEMIE-Eólico) is focused on increasing and consolidating the country's scientific and technical capacities in the field of wind energy.

2.0 National Objectives

2.1 Targets

The 2015 Energy Transition Law, together with the Electricity Law, provides the legal framework to accelerate deployment of power generation from clean energy (defined as renewable sources, nuclear, high-efficiency cogeneration, waste-based generation, and thermal power plants with carbon capture and storage). México's targets for clean energy with respect to total electrical generation are: 35%, 37.5%, and 50% for 2024, 2030, and 2050, respectively [1, 2].

México has abundant renewable energy resources. Reliance on wind, geothermal, and photovoltaics has been limited thus far, but the potential for growth is enormous and policies are increasingly supportive. Efforts to develop wind power in México are increasing; 3.5 GW of capacity are already in place, and there is potential for further development across large swathes of northern and southern México [3].

2.2 Policies supporting development

México's recent energy reform intends to foster competitiveness and private investment throughout the electric power sector value chain. This should increase port economic growth and job creation by delivering competitively-priced, reliable, clean, and secure electricity. The system is moving from a completely state-owned national utility, which provides everything from generation to transmission, distribution, and retail, to a highly competitive market [1]. The primary features of the new system include:

- Transformation of the Federal Electricity Commission (CFE) into several generation companies, which will ultimately become separate and independent distribution and retail companies.
- Creation of the National Centre for Energy Control (CENACE) in 2014 to perform operational control of the national electrical system and the operation of the wholesale electricity market, as well as expand and modernize the national transmission network and the elements of the general distribution networks corresponding to the wholesale electricity market [4].
- Providing independent power producers with market access via a new wholesale market for most of the country.
- Offering private entities with the possibility to get into the transmission business.
- Implementing an auction system.

Auctions aim to allow basic service providers to enter into long-term contracts in a competitive and prudent manner to meet the needs of power, cumulative electrical energy and clean energy certificates (CELs), to allow other responsible loading entities to participate, and to allow sellers to have a stable source income to support efficient investments in new power plants or to upgrade existing ones. The first two auctions were held in 2016 where the approximate cost of energy was 0.04 USD/kWh. A third auction is planned for April 2017.

3.0 Implementation and Deployment

3.1 Progress

The vast wind resource throughout the country makes wind energy a viable option for sustainable and diversified energy policies that will meet the objectives and goals established by law. México has a wind potential of more than 50,000 MW and requires only about 17,000 MW to reach the goal of generating 35% of electricity with clean technologies by 2024 [7].

As a result of the new policies and legal framework resulting from the country's energy reform, México's wholesale electricity market began operation in 2016. With those new policies and legal framework as the main drivers of the development, wind power in México has continued to grow and evolve. In 2016, México added 454 MW of new wind power capacity to the country's electricity grid, bringing the total capacity to 3,527 MW—about 5% of total generation capacity [1].

According to the planning scenario, the electric power consumption of the National Electrical System (SEN) projects an annual average electricity demand growth of 3.4% for 2016–2030. The regions with the greatest growth in consumption will be Baja California Sur, Northwest, Northeast, and Peninsular, with rates higher than the average growth of the entire system [5]. México will need a minimum of 57 GW of new capacity during 2016–2030, of which wind power is expected to cover at least 21% [1].

The first two auctions held in 2016 demonstrated the highly competitive nature of wind power in the country. For example, wind power was placed as the second most demanded technology in the second auction, with 3.87 TWh of the total energy allocated (equivalent to 43% of the total) and 41% of the Clean Energy Certificates [6]. In México, auction mechanisms allow the development of this technology at competitive prices.

Due to the start-up of new plants under construction and the winning projects of the first and second auctions, wind capacity is expected to triple in the coming years, with 2,456 MW at the end of 2018 and another 3,857 MW at the end of 2019. In the period from 2016–2030, an estimated 12,000 MW of new capacity will be installed, of which 53% (6,358 MW) is currently under construction or approved to start construction [8].

The capacity to add wind technology is concentrated in two periods (Figure 1). Between 2016–2020, 6.6 GW will be added, and between 2024–2027, the remaining 5.4 GW will be added. Wind-generated electricity will increase 350.2% over the period from 2016–2030, to reach 15.1 GW of installed capacity and 47.4 TWh [8].

3.2 Operational details

México's 42 wind farms are located in the states of Baja California, Chiapas, Jalisco, Nuevo León, Oaxaca, Puebla, San Luis Potosi, Tamaulipas, and Zacatecas [1]. The key turbine manufacturers in the Mexican wind market are Acciona, Gamesa, and Vestas. To date, wind power has generated 6.9 billion USD (6.6 billion EUR) of new investment and an investment of 23.6 billion USD (22.4 billion EUR) is expected for the period from 2017–2020 [1].

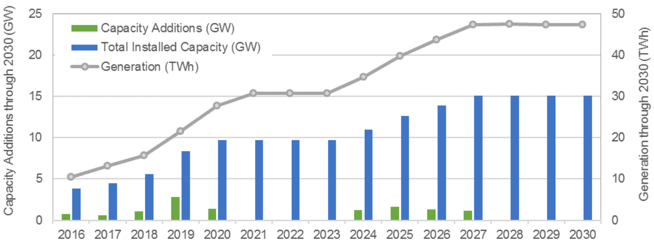

Figure 1. Anticipated evolution of additions, installed capacity, and generation of wind farms from 2016–2030 [8]

3.3 Matters affecting growth and work to remove barriers

The Energy Secretariat (SENER) has been carrying out a series of joint efforts with the CFE to form the National Inventory of Renewable Energies (INERE) and the National Atlas of Feasible Zones. SENER, in collaboration with the Technological University of Denmark and the National Institute of Electricity and Clean Energies (INEEL), will develop a map to provide quality information related to wind potential. This is part of a project called the Mexican Wind Map, which will have a high level of resolution due to the precision of a robust modeling scheme, and is backed by the installation of 13 wind speed measurement stations. This map will be available in 2018 [9].

SENER also published the Program for the Development of the National Electricity System (PRODESEN), which contains the planning of the SEN following the coordination of two key programs for electricity sector development. In 2017, the "Program for the Expansion and Modernization of the National Transmission Network and the General Distribution Networks" will be published. The tender for the first line of electric transmission under new contract models will connect the Tehuantepec Complex with the center of the national territory via a 600-km, high-voltage direct current line [10].

Efforts to develop wind power in México are increasing; 3.5 GW of capacity are already in place and are on target to reach 12 GW by 2020.

Some of the challenges negatively affecting growth are [1]:

- The new legal and regulatory framework is still a work in progress, and some essential rules need to be defined further.
- CENACE needs to further clarify procedures and regulations linked to the trading of energy, forecasting, and quality of energy requirements in the new scenario.
- Electricity tariffs have been historically low during the past two years–though they are currently rising.
- Transmission infrastructure is constrained in regions with good wind resources; reinforcement of the power grid and additional transmission lines are needed.
- The requested level set for CELs for 2018 is not likely to be reached, as the projects providing the certificates will only be commissioned in the fourth quarter of 2018. This situation is expected to improve in the years to come, and the number of required certificates will increase annually until 2024.
- Interest groups and communities who don't directly benefit from wind power have expressed public opposition to wind power projects.

4.0 Impact of Wind Energy

The development of 12,000 MW of wind power by 2020 would help reduce emissions by more than 20 million tons of CO_2, equivalent to approximately 10% of the national mitigation target. In addition to the environmental benefits of reducing CO_2 emissions, developing wind technology brings multiple economic and social benefits. Wind-generated electricity brings energy to areas that have limited access to the service and strengthens the development of locations where large resources are located [7].

Table 1. Key National Statistics 2016: México

Total (net) installed wind power capacity	3,527 MW
Total offshore capacity	0.0 MW
New wind power capacity installed	454 MW
Decommissioned capacity	0.0 MW
Total electrical energy output from wind	14.236 TWh
Wind-generated electricity as percent of national electricity demand	4.80%
Average national capacity factor	34.46%
Target	12.8 GW in 2020
National wind energy R&D budget	10.9 million EUR; 10.4 million USD

México

Figure 2. The Regional Center for Wind Technology (CERTE) in Oaxaca, México (Photo credit: © INEEL)

5.0 R,D&D Activities

5.1 National R,D&D priorities

The Sectorial Fund CONACYT-SENER-Energy Sustainability (FSE) created the Mexican Centers for Energy Innovation (CEMIEs) to enable research and technological development, as well as to promote clean energy. The CEMIEs aim to link and consolidate the national renewable energy capacities to overcome the barriers and take advantage of the scientific and ecological opportunities for the sustainable use of energy. The CEMIEs are networks or strategic alliances that link and expand scientific-technological-enterprise fabric.

CEMIE-Eólico's main purpose is to increase and consolidate México's scientific and technical capacities in the field of wind energy. The Center builds synergy among national institutions so that activities on innovation, research, and technology aid in constructing a stronger national wind energy industry. CEMIE-Eólico's strategic objectives are:

- Increasing the reliability and availability of wind turbines and wind farms
- Reducing costs of operation and maintenance of wind turbines and power plants
- Achieving grid support at competitive costs and under reliable conditions
- Expanding the areas of application of the technology
- Developing a new generation of researchers specializing in the different subjects of wind energy

CEMIE-Eólico is led by INEEL and started operations in 2014, developing 13 projects that will be carried out over the following four years. To date, there are 33 member organizations in CEMIE-Eólico, of which includes 17 higher education institutions, seven private companies, five public research centers, two foreign universities, one foreign research center, and one state government unit.

5.2 R&D budget

At the end of June 2016, the FSE supported the geothermal, solar, and wind energy CEMIEs with a total of 78 million USD (74 million EUR). Additionally, in December 2015, 1.05 billion MXP (483,000 EUR; 504,000 USD) were authorized for the formation of CEMIEs for bioenergy and ocean energy.

Resources for CEMIE-Eólico have been approved in the amount of 10.38 million USD (9.86 million EUR), of which 5.8 million USD (5.5 million EUR) has been given, and a concurrence of 5.09 million USD (4.84 million EUR) is expected.

5.3 Research results

CEMIE-Eólico focused their research to develop smart solutions distributed generation and O&M, as well as to increase the use of nationally produced components in the value chain. In 2016, important progress (up to 90%) was made in following projects [11]:

- Development of a control system to modify wind turbine blade profiles by changing the geometry of a blade's cross section according to the speed of the incoming wind flow. This would allow the control system to maximize the absorption of wind energy by optimizing the efficiency of the energy conversion.
- Creation of an embedded telematics system to monitor and diagnose the dynamic performance of a wind turbine's mechanical transmission based on a wireless communication system and an expert data processing and analysis system to detect and predict.
- Development and strengthening of national manufacturing competences for the strategic metal-mechanical components of the power train for a medium-capacity prototype wind turbine (1.2 MWe). The turbines' hub, chassis, shaft, shaft support, and lifting structure for the chassis were manufactured in metal-mechanical national companies. The technical document containing the design information for a "Type D" evaluation of the prototype wind turbine design is also available.

Progress was also made on the following projects in 2016:

- Research and development of automated methods for the accommodation of composite layers applied to the manufacture of blades.
- Rotor design for horizontal axis wind turbines, incorporating one of three aero elastic innovation options, including construction and testing of a section.
- Integration and consolidation of national capacities for the development of small wind turbines through the design, construction, and exhaustive testing of a wind turbine with a capacity of 30 kW.

- Development of a blade manufacturing laboratory, focusing on blade design, blade manufacturing engineering, mold and tooling making, and blade making.
- Design, analysis, and construction of synchronous electric generators of permanent magnets and induction double fed for wind plants.

5.4 Test facilities

INEEL's Regional Centre of Wind Tecnology (CERTE) is situated on 32 hectares near La Ventosa, in Oaxaca, México with IEC61400-1 Class I or II wind power, depending on the height of the terrain. The facility's electrical substation and interconnection line can integrate up to 5 MW of wind power capacity. Two complete meteorological towers (80 m and 40 m) allow authorized users to monitor the installations from anywhere in the world, either in video or in data. One CEMIE-Eólico strategic projects at the CERTE test is making progress on the installation and testing of a 2-MW horizontal wind turbine with a 100-m concrete tower.

5.5 Collaborative research

The Mexican wind industry, CEMIE-Eólico, and its strategic projects addressed their technical goals by participating in international work such as IEA Wind TCP in 2016. México participates in Task 11 Base Technology Information Exchange and Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power. In 2017, Mexico plans to participate in Task 27 Small Wind Turbines in High Turbulence Sites.

México, through the Energy Secretariat, participates in a joint effort with National Resources Canada and the U.S. Department of Energy in the NARIS project aimed to analyze pathways to modernize the North American power system through the efficient planning of transmission, generation, and demand. Results will be published by 2019.

6.0 Next Term

The Mexican wind industry expects to install about 1,100 MW in 2017 in the eleven wind farms that are currently under construction. By 2020, the industry expects to see more than 12,000 MW installed, and up to 15,000 MW by the end of 2022 [1].

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Opening photo: Deployment of wind farms in La Ventosa, Oaxaca, México (Photo credit: © INEEL)

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the Netherlands

1.0 Introduction

The Netherlands is making strides toward the country's renewable energy targets: 14% renewable energy sources (RES) by 2020 and 16% RES by 2023 from total energy demand.

In 2016, two 700-MW offshore wind tenders set new trends in methodology and in cost-effectiveness. The result of tenders in June and December were 72.7 EUR/MWh (76.6 USD/MWh) and 54.5 EUR/MWh (57.4 USD/MWh) respectively. These tenders have set new offshore wind farm development standards for exploitation of the market to obtain very competitive prices.

The majority of new turbines were connected at the new Gemini offshore windfarm, ("The Twins," two 300-MW). Land-based wind progressed at a lower rate, with a net increase of 215 MW in 2016.

2.0 National Objectives

2.1 Targets

Since 2013, land-based targets for 2020 have been individually set per province (Table 2). On average, provinces have reached 51% of their 2020 targets, varying between 8% in Drenthe and 75% in Flevoland. The general speed of implementation is concerning, as there is an average of only 200-MW increase per year over the last five to ten years.

2.2 Policies supporting development

In 2011, the Encouraging Sustainable Energy Production (SDE+) subsidy was introduced for renewable energy, excluding offshore wind. This operating grant fills the gap between the market price of energy and the cost of electricity, heat, or gas produced in the renewable energy market. Each generating technique has a unique maximum allowed base tariff, and the cheapest option is granted first.

Applications can be submitted for the SDE+ throughout the year. Applications completed earlier in the year receive a lower SDE+ subsidy (but a higher chance for grant approval). In 2016, the total SDE+ budget increased from 3.5 billion EUR (3.7 billion USD) to 9.0 billion EUR (9.5 billion USD) Two rounds of land-based SDE+ tendering were completed during the year (Table 3).

Offshore, the Netherlands has moved from one-by-one deployment to a system of constant deployment. The country installed 3,500 MW of new capacity across two wind farm zones (Borssele and Hollandse Kust), which was broken down into five 700-MW tenders. Each tender consisted of two parcels of 330–350 MW each. This plan fosters a culture of innovation, technique, and approach, and aims for offshore wind costs to fall by 40% compared to 2014.

3.0 Implementation and Deployment

3.1 Progress

To achieve this goal of 40% reduction in offshore wind costs, the government mitigated risk away from industry by changing the legal framework for offshore wind energy. Thus, led to adopting special planning for the North Sea, as well as new acts on water, offshore wind energy, subsidies, and electricity and gas, and to established bidding constraints.

The only ranking criterion in the tender system is the price of the energy, expressed in EUR/MWh. The system reduces risk as much as reasonably possible, so that the bidder is able make an offer and optimize its project even after bidding—provided that it fits within the constraints determined by the legislative system. As a service to the bidders, the government started a series of six site investigations for the Borssele location: Metocean Measurement Campaign, Wind Resource Assessment, Archaeological Desk Study/Assessment, Geological Desk Study, Morphodynamics Desk Study, and UXO Desk Study. The investigations are free available helping bidders determine the cost of the wind farms and enabling them to offer a low bid.

Figure 1. Lagerwey Climbing Crane (Photo credit: Lagerwey)

In July 2016, the subsidy and permits for the Borssele Wind Farm Sites I and II (350 MW each) were awarded to DONG Energy Borssele 1 B.V. with an average bid strike tariff, excluding transmission costs, of 72.70 EUR/MWh (76.55 USD/MWh) during the first 15 years of the contract. At the time it was granted, this project was the biggest and cheapest offshore windfarm planned in the world.

In December 2016, the subsidy and permits for the Borssele Wind Farm Sites III (330 MW) and IV (350 MW) were awarded to Blauwwind II CV, a consortium of Eneco, Diamond Generation Europe (100% subsidiary of Mitsubishi Corporation), Shell, and Van Oord. The average bid strike tariff, excluding transmission costs, was 54.49 EUR/MWh (57.38 USD/MWh) for the first 15 years of the contract. Both wind farms will receive the market price after 15 years.

The government expects to spend 1.1 billion EUR (1.16 billion USD) on parcels I and II and 3.0 million EUR (3.16 million USD) on parcels III and IV. Maximum allowed tariffs were 124.00 EUR/MWh and 119.75 EUR/MWh (130.57 USD/MWh and 126.10 USD/MWh). Bid prices in 2016 were surprisingly low. Since the SDE+ subsidy only fills the gap between the market electricity price and the bid tariff, the needed subsidy is expected to be only a portion of the reserved budget. The reserved subsidy is 3.8 billion EUR and 5.0 billion EUR (4.0 billion USD and 3.27 billion USD), which means that total subsidy savings will be 7.4 billion EUR (7.8 billion USD).

3.2 Operation details

The Netherlands saw a very low wind index of 80% in 2016 (2015: 102%, 2014: 89%). This low "windex" leads to problems for the owners of old wind farms, which are relatively inefficient and have usually run out of subsidy, and are therefore only receiving the market price of electricity. However, increased turbine performance (increased hub height, increased swept area to power ratio) compensated for the low wind speeds; the land-based capacity factor in 2016 was 21.4%, which is nearly equal to the last 10-year average capacity factor.

Because the Netherland's installed capacity offshore nearly tripled, the capacity factor varied throughout 2016. A theoretical average offshore capacity factor was 39%, however, this calculation includes the 600-MW Gemini farm commissioned in December 2016.

3.3 Matters affecting growth and work to remove barriers

Social acceptance is one of the main obstacles in the Netherlands. Often, developers often underestimate the time needed for coordination with neighborhood residents, leading to delays. Also, the SDE+ subsidy is only available for a fixed time window once it is granted.

To help provinces meet their targets, a governmental team (RVO.nl) monitors and evaluates their progress. The most persistent bottlenecks are exemptions to the Law on Flora and Fauna. Often, application handling is conducted at high juridical levels and takes more time than expected.

Radar issues are limiting projects in northern and western Netherlands, including the planned 320-MW wind-in-lake farm in Friesland. New radar at Den Helder in the northwest mitigates these problems, but new problems could occur in the southeast of the country.

The planned expansion of Lelystad airport (overflow for Schiphol Airport) in the province of Flevoland also hindered project development due to uncertainties surrounding the allowed turbines tip height. This uncertainty was clarified in 2016.

The Netherlands fosters a culture of innovation, technique, and activity. The country is making strides toward their renewable energy targets: 14% Renewable Energy Sources (RES) by 2020 and 16% RES by 2023.

4.0 Impact of Wind Energy

4.1 Industry development

In 2016, the Lagerwey Company finished developing the L136. This machine has a 4.0- or 4.5-MW generator, a 136-m rotor and hub heights of 120 m, 132 m, or 166 m. The development of the self-climbing crane makes it possible to avoid using huge and expensive installation cranes.

Emergya Wind Technologies (EWT) installed 79 wind turbines in 2016, including its first in Turkey. The company services around 400 turbines in the 900-kW class in the UK. The 500-750-900 kW range with a 61m rotor is impressive, increasing the specific area from 3.25 to 5.84 m2/kW. EWT is the first wind turbine company to win the prestigious Bloomberg New Energy Pioneer award for its commercial and technical innovations in 2016.

The Netherlands is also home to several suppliers, transportation, installation companies, as well as those in the knowledge arena (controls, aerodynamics, strength calculations, commercial wind turbine test sites, etc.).

5.0 R,D&D Activities

5.1 National R,D&D priorities

Since 2012, R&D programs for wind energy in the Netherlands have only focused on offshore wind energy. The Topconsortia for Knowledge and Innovation (TKI Wind Offshore Wind) coordinates these programs, representing the R&D community and the industrial sector.

In 2016, one R&D tender was specifically dedicated to offshore wind with a budget of 5.4 million EUR (5.7 million USD). The tender was oversubscribed, and eight of the 16 submitted applications were

Table 1. Key National Statistics 2016: the Netherlands

Total (net) installed wind power capacity	4,206 MW
Total offshore capacity	957 MW
New wind power capacity installed	815 MW
Decommissioned capacity	---
Total electrical energy output from wind	8.159 TWh
Wind-generated electricity as percent of national electricity demand	6.8%
Average national capacity factor *	Land-based: 21.4% Offshore (estimated): 39%
Target	14% RES by 2020; 16% RES by 2023 (from total energy demand)
National wind energy R&D budget	9.8 million EUR/year as 5-year average

* Capcity factor calculation: (installed 1st Jan + installed 31st Dec)/2.

> **The Netherlands has moved from one-by-one deployment to a system of constant offshore deployment.**

approved with a subsidy rate of approximately 71% (subsidy vs. project costs). Most of the awarded projects have an industrial research profile or are working closely with knowledge institute.

Two general renewable energy programs accept land-based wind R&D projects. Six additional applications were approved totaling 6.5 million EUR (6.8 million USD) with an average subsidy level of 67%. Including one feasibility study, 15 wind energy projects and 11.8 million EUR (12.4 million USD) were granted. The five-year average is 9.8 million EUR/yr (10.3 million USD/yr). The following is a partial list of approved projects [1].

Self-climbing crane (Lagerwey): Demonstration project for assembling land-based wind turbines—reducing the physical footprint and cost to erect turbines, and making higher hubs possible. While 165-m crane weights around 2,500 metric tonnes, the self-climbing crane weighs around 90 metric tonnes. The shorter crane arm results in less movement and higher accuracy during lifting, making it possible install during higher wind speeds (up to 15 m/s). Using this technique can help developers avoid the high costs of a conventional crane (Figure 1).

NHLO: Seaqualizer—prototyping and testing an offshore access bridge with a spring balanced motion compensation system, enabling payload transfers up to 450 kg over a 26-m bridge at angles between -25° and +25°. Because the whole system is under pre-tension (like an anglepoise lamp), the bridge needs fewer than 100kW of hydraulic power to compensate for wave activity.

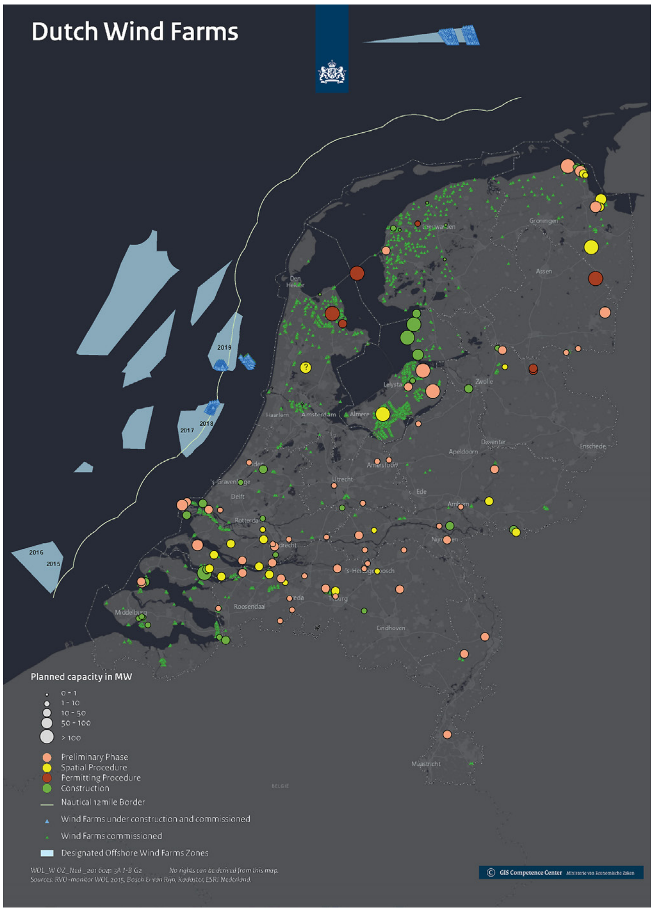

Figure 2. Dutch wind farm in planning/under construction (Photo credit: RVO.nl)

Marin: Improving Safety and Productivity of Offshore Wind Technician Transit (DEMOWIND-2) project is developing a model and a tool for technicians as they transport to offshore wind turbines in different sea conditions. The tool will measure the motion of the boat and the underlying sea state, enabling technicians to make a responsible decision regarding whether or not to launch.

Marin: A joint industry project for improving engineering methods for logistics for handling gravity-based (GBS) wind turbine foundations. This should result in more effective and safer operations with better working conditions and optimized logistics.

ECN:Wind Farm Control Trials (DEMOWIND-2) is a series of full-scale wind farm control trials, in which the controllers of the individual wind turbines are made subservient to a main wind farm controller, optimizing loads and output as one entity. Pitch and yaw based wind farm control might lead to a 0.5–3.0% increase in energy yield, and up to 50% load reduction for some components.

ECN: Improving and validating structural models for large flexible blades is developing torsion models and modeling aero-elastic behavior, toward in a new 10-MW blade design.

Scholt Energy Services: Demonstration of a 1-MW/1-MWh Li-ion battery in a 9-MW windfarm and the develops new algorithms for controlling the system, thereby optimizing the local energy system.

Deltares: —Simulatiing monopile installation to investigate drivability and monopile behavior. This project will lead to design tools calibration recommendations and installation techniques.

Temporary Works Design B.V.: This project designs an integrated blade installation method, including a lifting tool dedicated to blade installation and removal. The goal is to transfer blades along a truss-shaped boom from a vessel to a semi-fixed support point on the tower near the nacelle. From this position,

Table 2. Installed Capacity and 2020 Targets Per Province

	2020 Target (MW)	Installed Capacity in 2015 (MW)	Percent of Target 2015 (%)
Flevoland	1,391	1,039	75%
Zeeland	571	360	63%
Noord-Holland	686	360	53%
Groningen	856	444	52%
Overijssel	86	43	50%
Zuid-Holland	736	341	46%
Utrecht	66	25	38%
Friesland	531	169	32%
Noord-Brabant	471	143	30%
Gelderland	231	59	26%
Limburg	96	18	19%
Drenthe	286	22	8%
the Netherlands (total)	**6,001**	**3,034**	**51%**

Table 3. SDE+ Subsidies Granted in 2016 [2]

	Number of Grants	Money Granted (million EUR; million USD)	Power Capacity Granted (MW)	15-yr Production (GWh)	Tariff (EUR/MWh; USD/MWh)
SDE+ Subsidies					
Wind (land-based)	94	784; 826	326	15,258	---
Other (excluding offshore)	3,089	8,216; 8,652	3,552	140,529	---
Total (excluding offshore)	3,183	9,000; 9,477	3,878	155,787	---
Offshore Wind					
Borssele I	1	1,135; 1,195	376	26,645	71.59; 75.38
Borssele II	1	1,170; 1,232	376	26,111	73.81; 77.72
Borssele III	1	581; 612	360	23,723	54.49; 57.38
Borssele IV	1	618; 651	376	25,222	54.49; 57.38
Total Borssele	**4**	**3,503; 3,689**	**1,488**	**101,699**	

technicians can install the blades with motions equal or less than conventional installation.

Ampyx Power B.V.: Airborne Offshore Wind Farm is a conceptual design of a 2-MW offshore-adapted airborne generator (Ampyx) and offshore support structure (Mocean) in a 350-MW offshore windfarm. A model will analyze, scale, and evaluate concepts for the airborne generator, the support structure, and how these interact. Installation, O&M, decommissioning and levelized cost of energy will also be modeled and the model will interactively be used in the designing runs.

Stichting Deltares: This project develops a clear, generic, and science-based comparison between different scour protection methods with the goal of selecting the most suitable and cost-effective scour protection method for each situation. Along with existing methods (based on loose rock), the project will investigate and optimize new innovative scour mitigation methods and make them available for offshore field tests.

KCI the engineers B.V.: Designs, tests and validates the Double Slip Joint (DSJ) for offshore wind, a cylinder with a set of two conical rings welded to it, connecting the tower to the monopile. Because the contact area on the rings is smaller, the contact pressure is higher. This enables the optimal transfer of friction, better adjustment of the shape, and better fitting, resulting in no slip or uncontrolled corrosion.

In 2016, the FLOW R&D project stopped and its successor, GROW started as a consortium of 16 companies and knowledge institutes in the Netherlands which will execute a common R&D program. The project has two main objectives:

- Expand the role of offshore wind in the energy system by reducing costs, increasing value (including the system's reliability, stability, and symbiosis with other sectors at sea), and limiting the environmental effects of offshore wind
- Strengthen the Dutch offshore wind sector by developing new products and processes for projects in the Netherlands and abroad.

The total GROW budget will be an estimated 100 million EUR (105.3 million USD) from 2017–2021 and will cover Technology Readiness Levels 2 to 8. GROW participants have asked the Dutch government to provide a significant portion of the long-term funding to ensure the continuity of the five-year program. The government will decide on funding GROW in 2017.

5.3 Research results

In 2016, two projects from the TopSector policy came to an end [1]:

- The Fistuca Blue Piling projectdemonstrated piling with a blow of gas. A column of water gives reaction force, which is pushed upwards and hits the monopole a second time when the water falls down. This technique gives less (under water) noise and reduces fatigue usually introduced when hammering.
- Wifi Joint Industry Project modeledhow braking waves impact the support structures of offshore wind turbines.

5.4 Collaborative research

In 2016, the Netherlands joined IEA Wind TCP Task 35 Full-Size Ground Testing for Wind Turbines and their Components, and Task 37 Wind Energy Systems Engineering: Integrated Research, Design, and Development. This brings the Netherland's participation to 11 of the 15 running IEA Wind TCP Tasks.

6.0 Next Term

The SDE+ budget is expected to increase to 12 billion EUR (12.6 billion USD). In addition, there will be the third tender in the series of five tenders for 700-MW offshore wind projects. This tender will be first in the "Hollandse Kust" zone. However, the 2017 elections and other major decisions may affect the implementation of the Paris Agreement in the Netherlands.

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Opening photo: Wind turbines along the A12 highway in the Netherlands are becoming part of the horizon. (Photo credit: André de Boer)

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Norway

1.0 Introduction

In 2016, no new wind power capacity was installed in Norway; however, investment decisions made during the year suggest that over 1,700 MW of new capacity will be built by the end of 2020. Installed capacity totaled 873 MW at the end of the year, and production of wind-generated electricity totaled 2.125 TWh (compared to 2.512 TWh in 2015).

Wind resources in 2016 were considerably lower than normal. The wind index for Norwegian wind farms was 95%, corresponding to a production index of 92%. The average capacity factor for Norwegian wind farms in normal operation was 29%. Wind-generated electricity amounted to 1.4% of the total electricity production in the country, offsetting 1.6% of total demand.

Norway's electricity production includes a high share of renewables. The primary source is hydropower, which accounted for approximately 96% of the country's electricity production in 2016 alone and exceeded demand by 10.9 TWh.

2.0 National Objectives

Renewable sources amounted to 97.7% of the national electricity production in Norway in 2016—1.4% of which came from wind power. There was a net electricity export of 16.4 TWh, as electricity consumption in the country totaled 133.1 TWh for the year. The high ratio of renewable energy production, combined with concern over local environmental impacts, has fueled public debate on Norway's wind power development in recent years.

As a member of the European Economic Area (EEA), Norway accepted the European Union's (EU) renewable energy directive in 2011. The nation's target for renewable energy was set to 67.5% of total energy consumption by 2020. Norway will meet this target through a combination of energy efficiency measures and increased renewable energy production.

2.1 Targets

The incentive mechanism for increasing renewable energy production in Norway is a joint support scheme with Sweden to finance 28.4 TWh/yr of new renewable energy capacity by 2020. This market-based electricity certificate scheme is unique as the targets are both country- and technology-neutral.

The policy does not dictate which country the new renewable energy production comes from, nor does it dictate the generation technology. Rather, the policy objective is to allow the market to dictate the location and type of renewable energy capacity, ensuring a cost-effective increase in renewable energy production from a macroeconomic standpoint.

In practice, this policy means that Norway has no explicit wind energy target. However, the electricity certificate scheme resulted in investment decisions to build considerable wind energy installations in Norway by 2020.

2.2 Policies supporting development

Enova SF provided financial support for wind power projects in Norway from 2001-2010. The state-owned organization awarded funding on a case-by-case basis, supporting projects just enough to make them commercially viable. This program terminated in 2011, although the last projects to receive support were commissioned in 2012 and 2013.

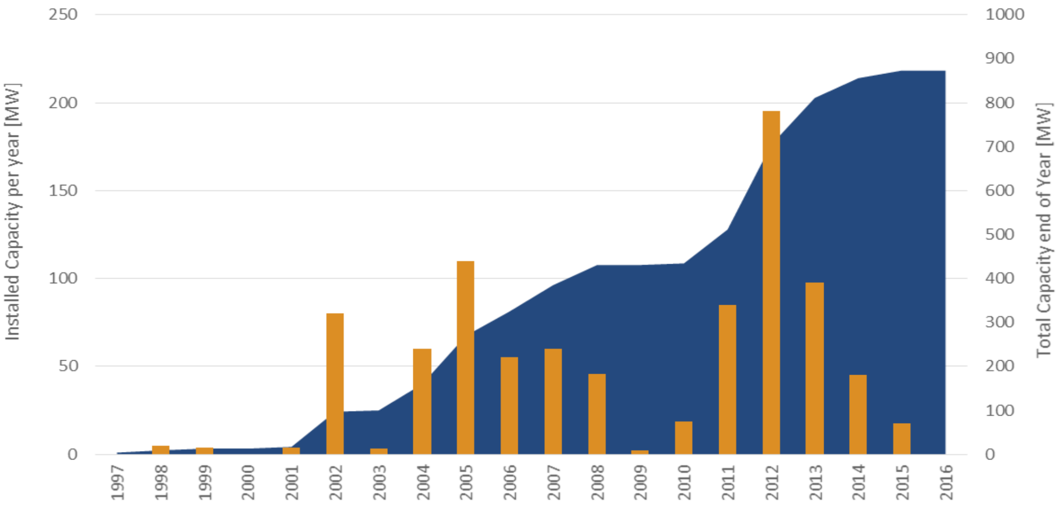

Figure 1. Installed capacity in Norway per year (orange) and cumulatively (blue), from 1997–2016

In 2012, Norway and Sweden entered into a common electricity certificate market scheme. The economic incentive provided by the electricity certificate scheme aims to develop a combined 28.4 TWh/yr of new renewable power production in the countries by the end of 2020. Norwegian power consumers are expected to finance 13.2 TWh of this new power production.

The certificate system shifts the cost of supporting renewables from Enova to the electricity consumer. Approved power plants receive one certificate for every generated MWh from renewable energy sources for 15 years after commissioning. Owners of approved plants then have two independent products on the market: electricity and certificates.

The demand for certificates is created by a quota obligation—a requirement that all electricity users purchase certificates equal to a certain proportion of their electricity use. The market then determines the price of certificates by supply and demand, varying from one transaction to another.

In April 2017, the Norwegian and Swedish governments reached an agreement on the electricity certificate scheme's future after the original deployment cut-off in 2020. The agreement extended the cut-off for Norwegian projects by one year; wind power in Norway must be commissioned by the end of 2021 to receive support from electricity certificates. There is no plan to subsidize new wind power in Norway after 2021, therefore any wind power realized in Norway after that year will have to be profitable based upon electricity sales alone.

Additionally, the agreement dictates that Norway will not expand beyond their current existing target for power production (13.2 TWh of new renewable energy). In contrast, Sweden has elected to expand its target to add an additional 18 TWh of new renewable production by 2030 within the electricity certificate scheme. Norway and Sweden have also agreed to continue trading certificates in a common market, even after the 2021 cut-off for Norwegian wind farms. Due to the new target in Sweden, the demand and market for certificates will be extended until 2045.

3.0 Implementation and Deployment

Enova SF supported the development of over 700 MW of wind power commissioned between 2001 and 2013. Deployment of wind power has been modest in the first years of the electricity certificate scheme, with 120 MW of wind power approved in the scheme as of the end of 2016. Figure 1 shows the history of deployment of wind power in Norway from 1997-2016.

Figure 2. Seatower has developed a gravity based foundation with crane free installation. A pilot foundation supports a met mast at the planned Fécamp wind park in French waters. (Photo credit: Seatower)

Over 1,200 MW of wind power capacity was under construction in Norway at the end of 2016, with investment decisions made for nearly 500 MW of additional capacity by 2020.

3.1 Progress

Norway entered into the electricity certificate scheme with Sweden at the start of 2012. So far, six wind power plants have been approved for the scheme, totaling 120 MW. However, investment decisions for Norwegian wind power plants within the electricity certificate scheme increased dramatically in 2016. In early 2016, plans were announced for the deployment of 1,000 MW of new wind power in central Norway in the coming years, as well as several investment decisions for smaller wind projects.

As of the end of 2016, over 1,200 MW of wind power capacity was under construction throughout Norway, with investment decisions made for nearly 500 MW of additional capacity by 2020.

3.2 Operational details

In 2016, annual wind speeds were lower than normal at all Norwegian wind farms, resulting in a wind index of 92% nationally. The capacity factor of wind farms in normal operation varied between 20–47%. The generation weighted average capacity factor was 29% for wind farms in normal operation 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 636–1,702 kWh/m^2, with a national average of 1,068 kWh/m^2.

4.0 Impact of Wind Energy

4.1 Economic benefits

Norwegian industry takes part in component production for wind energy systems, such as wind turbine blades and nacelles, on a relatively small scale. Companies with experience from the offshore oil industry (e.g., 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.

Table 1. Key National Statistics 2016: Norway	
Total (net) installed wind power capacity	873 MW
Total offshore capacity	2 MW
New wind power capacity installed	0 MW
Decommissioned capacity	0 MW
Total electrical energy output from wind	2.1 TWh
Wind-generated electricity as percent of national electricity demand	1.6%
Average national capacity factor	28.7%
Target	---
National wind energy R&D budget	10.3 million EUR; 10.8 million USD

Figure 3. With Seatower's Cranefree Gravity® foundation, seawater flows into a hollow foundation at the base of a turbine. This fixes the structure to the seabed, speeding up installation time and minimizing risk. (Photo credit: Seatower)

Increased construction of wind farms will generate engineering and construction jobs, as well as jobs for maintenance personnel.

4.2 Industry development

Several energy companies participate in the production of wind power, including large national energy companies and small local utilities. Foreign investment is becoming increasingly common in Norwegian wind power projects. Some Norwegian companies (Fred Olsen Renewables, Statkraft, and Statoil) are also engaged in projects abroad, such as offshore wind in the United Kingdom. So far, there is no significant wind turbine manufacturing industry in Norway.

5.0 R,D&D Activities

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 sectors.

These centers receive half of their funding from the Research Council of Norway, and the remainder is jointly funded by industry and the research institutions. NORCOWE and NOWITECH were established in 2009 with funding for eight years. Therefore, 2017 will be their last year with public funding, but hopefully the centers will continue research at their host institutions.

The Research Council of Norway also administers a public research program for sustainable energy, known as 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 based upon proposals to regular calls.

The Norwegian energy agency, Enova, offers capital grants for full-scale demonstration projects of 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 environmentally-friendly technology, including wind energy. The program supports projects with up to 45% of eligible costs.

5.1 National R,D&D priorities

Energi21 is the Norwegian national strategy for research, development, demonstration, and commercialization of new energy technology.

The R&D priorities for offshore wind are:

- Optimal foundations for both seabed-based and floating turbines and different seabed conditions
- Concepts and systems for reliable electric infrastructure (offshore subsea solutions)
- Cost-effective, time-saving assembly and installation of offshore wind farms
- Efficient concepts for marine logistics (heavy maintenance) and robust solutions for access
- Concepts and systems for reducing operational and maintenance costs and increasing energy conversion ratios
- Enhanced knowledge about offshore wind power's environmental and societal impacts

The R&D priorities for land-based wind are:

- Wind resources (prognoses)
- Cost-effective operation and maintenance and technology
- Environmental and societal issues

5.2 R&D budget

The Research Council granted a total of 93 million NOK (10 million EUR; 11 million USD) to wind energy research in 2016. The budget for the ENERGIX program was 400 million NOK (44 million EUR; 46 million USD), and an increase is expected in 2017. In December 2016, the ENERGIX program granted funding to the following wind energy R&D projects:

- Coatings for reduction of leading edge erosion (Carboline AS, industrial innovation project)
- Tackling icing issues for wind energy production (Kjeller Vindteknikk AS, industrial innovation project)
- Operational control for wind power plants (SINTEF ENERGI AS, knowledge-building project for industry)
- Wave loads and soil support for extra-large monopiles (MARINTEK, knowledge-building project for industry)
- Identification and study of robust surfaces with icephobic properties for Norwegian power production and transmission systems (SINTEF Materials and Chemistry, knowledge-building project for industry)

The first two are industrial innovation projects and receive 50% public funding. The three others are large competence building projects at research institutes, which receive 20% industrial and 80% public funding. In total, ENERGIX is funding 13 R&D projects, and 20 industrial companies and five research institutes are involved in these projects.

5.3 Collaborative research

In 2016, Norway participated in the following IEA Wind TCP Tasks:

- Task 11 Base Technology Information Exchange
- Task 19 Wind Energy in Cold Climates
- Task 25 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 32 LIDAR: Lidar Systems for Wind Energy Deployment
- Task 33 Reliability Data: Standardization 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
- Task 37 Wind Energy Systems Engineering: Integrated Research, Design, and Development

Norwegian research institutions are also involved in collaborative research through EU EERA, Horizon 2020, Nordic Energy Research, and others.

6.0 Next Term

The next term will be dominated by the construction of large amounts of new wind power capacity in Norway. Installed capacity is expected to triple by 2020, based on public investment decisions as of the end of 2016.

Norway will not continue with Sweden in a post-2020 expansion of the electricity certificate scheme, so wind power built in Norway after 2020 will need to be profitable based on power sales alone.

Due to expectations of increasing power prices, continued reduction in wind power costs, and new foreign investors with lower required rates of return, Norway expects significant wind power additions in 2020 and beyond.

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Opening photo: Fakken Wind Farm (Source: NVE)

Authors: David E. Weir, Norwegian Water Resources and Energy Directorate; and Harald Rikheim, Research Council of Norway, Norway.

Portugal

1.0 Introduction

The wind energy sector reached a maturity status within the Portuguese power system in 2016. The country deployed an additional 279 MW of wind power capacity—representing the highest value since 2012. Portugal reached a total of 5,313 MW installed wind power capacity, which represents 40% of the total renewable operational capacity in the country [1].

In 2016, Portuguese wind farms produced 12.5 TWh, meeting 24% of the nation's electricity demand with wind energy [1–5]. For the second consecutive year, at certain hours wind energy covered more than 100% of the electricity demand without any technical problems reported by the Portuguese Transmission System Operator (TSO). The electricity production from renewable energy sources in 2016 reached 66% of the national consumption, and during four consecutive days in May, continental Portugal met 100% of its electricity needs with renewables [1–5].

The high contribution from endogenous resources enabled Portugal to reduce their dependency on foreign energy and exports exceeded imports for the first time since 1999 [3].

2.0 National Objectives

2.1 Targets

In April 2013, the Portuguese government established the national targets for renewable energy through the National Renewable Energy Action Plan (NREAP) 2013–2020 [6]. This action plan sets the target for wind power to reach an installed capacity of 5,300 MW by 2020, of which 27 MW are reserved for offshore wind.

For 2016, the NREAP's estimations for land-based and offshore wind farm installation were 4,915 MW and 27 MW, respectively. The total installed wind capacity was 5,313 MW, exceeding the estimation by 398 MW. In fact, the total installed capacity is now above the targets planned for 2020.

2.2 Policies supporting development

The NREAP renewable targets have not been adjusted since 2013. Therefore, the renewable targets previously set to 2020 are active and established as a 10.0% contribution for the transportation sector, 35.9% in the heating and cooling sectors, and 59.6% for electricity [3].

Portugal also took an important step toward the NREAP offshore targets in 2016 [7]. This governmental decision, approved after ensuring European funding for the offshore transmission cable, authorizes the construction of a floating offshore wind park with a 25 MW nominal capacity. The Decree Law 153/2014 maintains and regulates the national incentives for micro and mini generation [8]. Also, the 2015 feed-in tariffs remain valid for the existing installations during the statutory period. The mean tariff paid to the wind power plants in 2016 was 93.21 EUR /MWh (98.15 USD/MWh) [10].

Portugal has 5,313 MW total installed wind power capacity, representing 40% of the total renewable operational capacity in the country.

3.0 Implementation and Deployment

3.1 Progress

In 2016, Portugal added a net capacity of 279 MW, increasing the installed capacity by 55% compared to 2015 (Figure 1). The demonstration phase of the WindFloat (2 MW) prototype was completed and the prototype was decommissioned [7].

By the end of the year, the cumulative installed capacity was distributed over 257 wind farms with 2,722 wind turbines operating across the country. Since 2014, no new wind power capacity has been installed in the Azores and Madeira archipelagos [1].

The Portuguese wind power fleet generated 12.5 TWh, corresponding to 24% of electricity demand, compared to 23% in 2015. Despite the increase, the wind share of total renewable production was 37.4%, a decrease of 7% from the previous year. This decrease is due to increased hydropower production (which represented 50.1% of the total renewable production in 2016) that recovered from the dry year of 2015 [1]. The average production at full capacity stood at 2,349 hours, which corresponds to an increase of 1.9% with respect to 2015 (2,306 hours).

3.2 Operational details

Only two wind farms were connected to the grid in 2016. The Douro Sul project had the highest impact with a nominal capacity of 149 MW [3]. Part of the new wind turbines corresponded to expanding

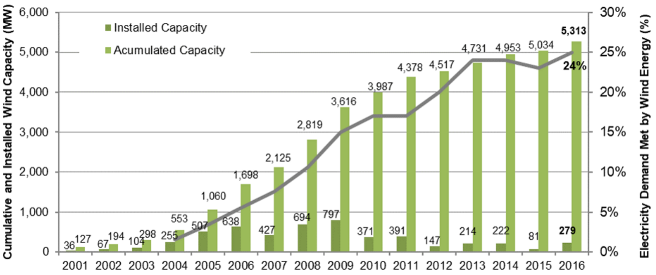

Figure 1. Installed and cumulative wind power capacities and share of wind energy in total renewable energy production (line graph) (Source: DGEG, REN and LNEG)

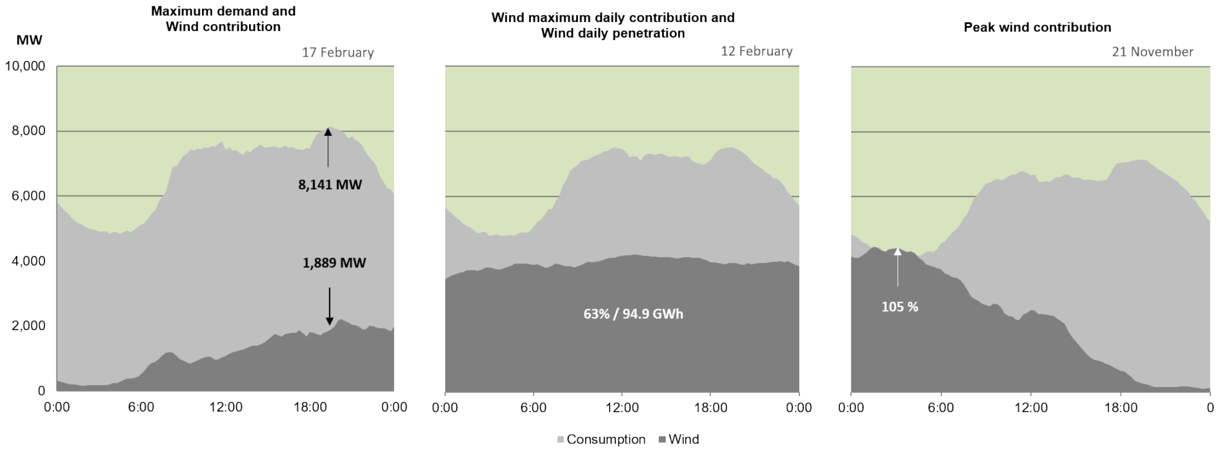

Figure 2. Wind power penetration and energy generation records during 2016 [2]

Portugal prepares for worlds first floating offshore wind park

The WindFloat is a novel offshore structure, combining a wind turbine and a semi-submersible platform. A full-scale prototype was placed in Aguçadoura, and it finished operating in 2016. During its lifetime, the system survived extreme wind and wave conditions with only minor requirements for maintenance. It achieved all foreseen milestones, such as surpassing the 17 GWh energy production mark.

The technology was fully scrutinized within the DEMOWFloat project. Researchers concluded that the wind- and wave-induced oscillations had a significantly reduced impact on the power performance of the WindFloat wind turbine. Consequently, the WindFloat technology was considered a successful demonstration project.

Following its success, WindFloat will continue into the second phase of its business plan: a pre-commercial phase with three or four wind turbines. This phase is expected to be operational in 2017 in the Viana do Castelo region. This project, which is co-funded by EC NER300, marks one of the first floating offshore wind parks in the world with 25 MW capacity [16–17].

the capacity of current wind parks—"overcapacity." Data from the Portuguese TSO indicated an annual wind generation index of 1.00. This represents a decrease of 1% when compared with 2015 [2].

Figure 2 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. The maximum instantaneous demand value was reached at 19:30 on 17th February 2016 but wind generation was only 1,889 MW. On 12 February 94.9 GWh of wind generated electricity were supplied, account ting for 63% of the daily demand, the highest in 2016 [2]. On 21 November 2016 wind power penetration was above the national consumption from 01:30 until 04:15, and the highest instantaneous penetration of 105% was recorded at 03:15. Despite these high wind penetration events, the TSO did not report any technical problems.

3.3 Matters affecting growth and work to remove barriers

The Portuguese government maintained a suspension of allowing new capacity for grid connection to re-evaluate the legal framework for electricity generation [9]. Therefore, the land-based wind projects that were deployed during 2016 account for capacity that was previously licensed, but still not installed, as well as wind park "overcapacity."

4.0 Impact of Wind Energy

4.1 Environmental impact

In 2016, the Wind generated electrical energy induced an income of 1,130 million EUR (1,189 million USD) for the wind power plant developers, and saved 5.3 million tons of CO_2 emissions (considering a factor of 430g/kWh). Based on data from the yearly contribution of each technology in the Portuguese energy mix, imports, and the consumption index, Portugal's dependence on fossil fuels was calculated at nearly 35%–a slight reduction compared to 2015 (Figure 3).

Coal is the cheapest fossil fuel for generating electricity and predominately fulfills Portugal's fossil fuel dependency. Despite this, the nation's natural gas contribution increased for the second consecutive year. Increased contributions from natural gas and endogenous resources reduced CO_2 emissions by nearly 6% to nearly 15 million tons (MT) in mainland Portugal [3]. Madeira Island also observed a reduction of nearly 4% of the CO_2 emissions to nearly 0.4 MT.

With the increase of contribution from the endogenous resources, the Portuguese power system reverted the energy foreign balance tendency. Exports exceeded imports in Portugal by nearly 10% in 2016. This result is particularly relevant since an increase in the electricity consumption to 49.3 TWh (Portugal mainland) was also observed.

Table 1. Key National Statistics 2016: Portugal	
Total (net) installed wind power capacity	5,313 MW
Total offshore capacity	0 MW
New wind power capacity installed	279 MW
Decommissioned capacity	2 MW
Total electrical energy output from wind	12.5 TWh
Wind-generated electricity as percent of national electricity demand	24%
Average national capacity factor	27%
Target	5,300 MW
National wind energy R&D budget	N/A

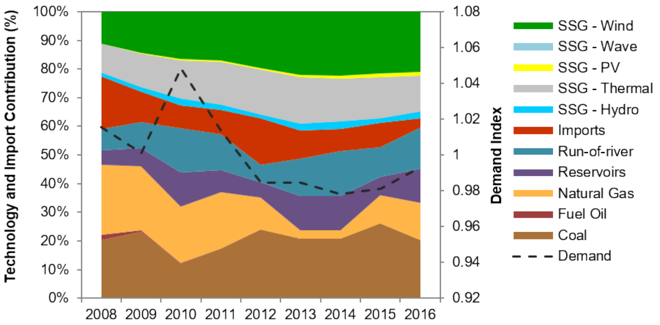

Figure 3. Yearly contribution from each technology and imports to the energy consumption and demand index from 2008–2016 in mainland Portugal (Source: REN and LNEG) [1]

4.2 Economic benefits

The wind industry and deployment activities in Portugal supported approximately 3,250 jobs. The average cost per MW installed in 2016 was 1.35 million EUR (1.42 million USD/MW). This amount includes associated costs for project installation and grid connection, among other expenses.

Turbine costs accounted for approximately 80% of the total installation costs and corresponded to approximately 1.308 million EUR/MW (1.377 million USD/MW). The mean tariff paid to the wind power plants in 2016 was 93.21 EUR/MWh (98.15 USD/MWh) [10].

4.3 Industry development

German wind power company Enercon remained in the leading position in the deployed wind power capacity during 2016. Enercon has 53.8% of the installed capacity. In second place is Vestas with a 12.9% share, followed by Gamesa 9.3%, Senvion (formerly REpower) 8.3%, Nordex 7.7%, GEWE 2.1%, Ecotècnia 2.1%, Suzlon 2.0%, Bonus 1.5%, and other manufacturers 0.6% [11]. In 2016 the majority of Portugal's wind turbines installed are Senvion MM92 and MM100 models.

5.0 R,D&D Activities

5.1 National R,D&D priorities

National R&D efforts during 2016 focused on offshore wind energy, and development of tools and methodologies to maximize the penetration of renewable energy, not only from a grid security operation point of view but also from a market perspective.

Most R&D activities are taking place at the main Portuguese institutes and universities and are funded through national and/or European programs. A call for funding the implementation phase of the research infrastructures included in the Portuguese Roadmap for Research Infrastructures took place in July and the Portuguese node for the European Research Infrastructure WindScanner.EU was submitted.

5.2 R&D budget

The total investment for science and technology was in the order of 500 million EUR (526.5 million USD) through to the Portuguese Foundation of Science and Technology (FCT). Approximately 101 million EUR (106.4 million USD) was for R,D&D and Innovation projects and 47 million EUR (49.5 million USD) to scientific jobs [13].

These figures represent a 4.7% increase since 2015 in total. However, the investment in R,D&D and scientific jobs decreased 18.3% and 5.4% respectively, when compared with projected 2016 values [14].

5.3 Research results

Initiatives to develop innovative gravity foundations models to support offshore wind turbines are currently ongoing within the DEMOGRAVI3 project [15].

The WindFloat prototype completed its demonstration phase at Aguçadoura during the summer of 2016. This concept structure proved to be a technically viable solution for floating deep offshore wind plants. It is expected that the first floating offshore wind park installed in 2017 will be based on WindFloat technology. The project is currently in the pre-commercial phase.

5.4 Test facilities and demonstration projects

Ongoing R&D activities are as follows:

- OPTIMUS: an FP7 project using demonstration methods and tools to optimize the operational reliability of large-scale industrial wind turbines.
- DemoWFloat: FP7 Project to demonstrate the sustainability of the Wind Float technology deployed in Portuguese waters.
- Research Infrastructure (RI) WindScanner.PT: constitutes the Portuguese node for the European Research Infrastructure WindScanner.EU. This RI will use a high precision remote sensing technology to measure the 3D wind for scientific, industrial and meteorological purposes in the wind sector. he RI will also include an open access platform and advanced training actions. At the end of 2016 the funding for the implementation phase was under evaluation.

5.5 Collaborative research

Portugal participates in IEA Wind TCP Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power. Portugal collaborates in IEA Wind TCP Task 30 Offshore Code Comparison Collaboration, Continued, with Correlation (OC5) through WavEC, IST/Centec with a participation co-sponsored by EDP-Inovação.

In addition to the IEA Wind activities, Laboratório Nacional de Energia e Geologia (LNEG) is the Portuguese representative in the European Energy Research Alliance Wind Program (EERA-Wind), a European initiative that integrates the leading European research institutes in the energy sector and aims to strengthen, expand, and optimize EU energy research capabilities.

In Portugal, LNEG and other Portuguese R&D entities are active partners in international research efforts.

- **IRPWind:** an FP7 project combining wind energy research projects and activities to foster innovation, collaboration, and knowledge transfer between European researchers and leading R&D entities, with the participation of EERA Joint Programme on Wind Energy partners
- **ETIPWind:** an H2020 project to create a virtual and physical platform through which the wind energy community can communicate, coordinate, and collaborate on work and activities related to R&I&T to reach the RES targets for 2020. The Portuguese contribution to this project is mainly on facilitate the sustainable integration of wind energy into the EU grids. Portuguese partner is EDP Renewables.
- **AEOLUS4FUTURE:** an H2020 project aims to develop sustainable and efficient wind energy systems for a variety of EU needs

- **DREAM-GO:** an international project focused on developing a more sustainable and efficient energy system, based on intensive use of renewable energy and active management of consumers
- **NEWA:** an FP7 ERA-NET project concerning the development of the new wind atlas for land-based and offshore wind in European countries
- **OceanNET:** an FP7 to educate a new generation of engineers and scientists on floating offshore wind and wave renewable energies to support the emerging offshore renewable energy sector
- **LEANWIND:** an offshore wind farm lifecycle and supply FP7 project to develop innovative technical solutions to optimize offshore wind farm deployment, operation and maintenance, as well as decommissioning procedures
- **RICORE:** an H2020 project to establishes a risk-based approach to consenting novel technology of offshore renewable energy systems on its environmental sensitivity in the deployment site
- **FORESEE:** the IEE training project for renewables and energy efficiency in building sector putting into practice the priorities identified in the Roadmap 2014–2020, under the Build Up Skills—Portugal

6.0 Next Term

Because Portugal is on track to reach the main goals for land-based wind capacity installation (with few pending licensing procedures), and because the share of wind energy is already at the highest values in the world, land-based wind energy installation is expected to stagnate in 2017.

Also, the NER300 and InnovFin programs (with support from the European Commission and the European Investment Bank, respectively) will implement the first floating offshore wind park on the Portuguese coast (and around the world) with 25 MW in 2017 [16–17].

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Opening photo: Wind Farm in Portugal. (Photo credit: Vitor Andrade)

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Spain

1.0 Introduction

Throughout 2016, wind power was the second source of electricity generation in Spain. In February, wind power was the largest source with a share of 30.2%.

The Energy Planning of the Government, which committed to install about 6,400 MW of new wind capacity and invest about 7.5 billion EUR (8.51 billion USD) to meet European targets for 2020, is delayed.

The Spanish wind sector installed only 38 MW during 2016 [1]. In a February auction, 500 MW of wind power capacity was allocated in contracts with no subsidy over the market price. A second call was approved with new contractual parameters for 450 MW planned for the Canary Islands after allocating only 15 MW in the first call. In 2017, industry will publish auction conditions for another 3,000 MW of wind power capacity.

National investments for wind related R&D totaled 85.5 million EUR (90 million USD) in 2016.

2.0 National Objectives

Spain's electricity sector reform in 2012 interfered with the 2011 target for 35 GW of wind power capacity through the National Renewable Energy Action Plan (NREAP 2011-2020) [2]. The reform significantly reduced incentives for existing wind farms; this regulatory uncertainty led to a dramatic reduction in new projects.

2.1 Targets

According to the Ministry of Industry, Energy and Tourism's 2015 energy planning exercise, renewable energy sources should satisfy 36.6% of Spain's gross energy generation by 2020 [3]. This target will likely be achieved with the most competitive technologies: wind and solar PV energy. However, all clean energy technologies compete in the government's technology-neutral auctions.

Spain's wind power capacity forecast is 29,400 MW. To meet the national target, the country will require 6,400 MW of new capacity by the end of 2020.

2.2 Policies supporting development

In October 2015, the government negotiated with the wind sector on the Wind Industry Relaunch Plan (PRIE), a 15-point cross-ministry program aimed at boosting the country's wind industry export value by 35%, to 3 billion EUR (4.6 billion USD) annually [6].

At the end of 2015, the government decided to consider promoting new renewable projects. The basis of a "reasonable return" of 7.4% for renewable projects commissioned after 2004 was established. Then in 2016, the government implemented auctions to support renewable energy in Spain with a focus on the reduction of the total capital expenditures (capex) for the installation. The maximum investment retribution for bidders was established at 63.243 EUR/MW (66.58 USD/MW).

The baseline capex amount is 1.2 million EUR/MW (1.26 million USD/MW); bids below this amount will not receive remuneration. Spain established the baseline capex using a reference wind facility with the "reasonable return," capacity factor of 2,800 equivalent hours per year, 20-year expected lifetime, and a baseline operating expenses (opex) of 24.95 EUR/MWh (26.27 USD/MWh) for the first year.

More than 6,000 MW registered for the February 2016 auction for 500 MW, creating high competition among bidders. The auction attracted independent developers such as a small power generation company (300 MW) and a meat processing company trying to diversify (102 MW). Eight small developers were accepted. Each bid was under the baseline capex of 1.13 million EUR/MW (1.19 million USD/MW) and forewent any subsidy.

Possible reasons for rejecting the subsidy bonus could include the long list of old, partially developed wind projects that were stopped due to the energy reform. Major developers believe it is not possible to promote viable wind farms without subsidies.

3.0 Implementation and Deployment

Spain installed 38 MW of new wind power capacity in 2016. These installations included 32 MW assigned under a previous program, 4.8 MW in Canary Islands, and 2.1 MW for repowering in Galicia. After the government's energy reform, only 68 MW have been installed in the last three years (Figure 1). For this reason, the Spanish wind manufacturing sector has been forced to export almost 100% of its products.

3.1 Progress

Land-based wind power capacity increased 38 MW to 23,026 MW in 2016. Wind-based electricity generation was responsible for 47.69 TWh/yr, representing 19.2% of total electricity generation. Wind-based electrical generation increased 1.7%, becoming the second largest source of electricity generation in Spain (Figure 2).

To accomplish the European targets, around 6,473 MW of new wind capacity needs to be installed before 2020. In 2016, 500 MW new wind capacity was awarded and another 3,000 MW should be awarded in 2017.

3.2 Operational details

The Spanish wind energy sector developed four wind farms in 2016. Two wind farms obtained Feed-in-Tariffs (FiT) under the old regulations: a 27-MW wind farm with Vestas wind turbines and a 4.5-MW with three Vensys 1.5 MW wind turbines. Two 2.4-MW Enercon wind turbines were installed on Lanzarote in the Canary Islands.

A 23-year old 3.9-MW wind farm in Galicia was also repowered in 2016, replacing 20 180-kW MADE AE20 turbines, one 100-kW Vestas V20, and one 200-kW Vestas V25 turbine. The new installation—two 3-MW Vestas V90 turbines—increases the energy production >400% and increases the power by 40% with an 8 million EUR (8.42 million USD) investment. Current regulations limit repowering to a 40% increase over the former rated power.

Galicia pioneered wind energy development, and wind farms in that area are scheduled for repowering. Throughout Spain, 12 GW of wind power capacity has been operating for more than 10 years, with more than 3.5 GW operating 15 years or longer.

Several new experimental wind offshore projects progressed in 2016, especially in the Canary Islands, due to the high price of energy.

- Plans for the first offshore wind farm in Spain were announced: the Mar de Canarias Wind Farm with two 5-MW wind turbines located 2.1 km off the southeast coast of Gran Canaria island.
- The 25-MW PLOCAN5 project will have five floating wind turbines using new hybrid semi-spar concrete platforms developed by COBRA.
- The 5-MW ELISA demonstration project will employ an innovative self-buoyant foundation platform developed by ESTEYCO.

The highest penetration of RES occurred on 31 January 2016, covering 100% of the power demand for eight hours with the 12 MW Wind-Hydro System installed on Hierro island in the Canary Islands.

3.3 Matters affecting growth and work to remove barriers

Many older wind farms are operating under the new "reasonable return" remuneration mechanism at a lower rate under the Energy Reform.

Some developers complain that the regulations forecast artificially high market prices from the previous half-year, causing reductions in the next three years. The Energy Reform left one-third of Spanish wind farms without regulated remuneration. During periods of high wind and low prices, some facilities have difficulty covering their O&M costs. Additionally, because auction conditions are updated within the regulatory framework every six years, they are seen as risky investments.

On the other hand, around 3.5 GW are used for adjusting the Spanish electrical system. Developers expect to increase the wind power capacity in balancing market to 50% of the cumulated wind capacity. Currently 15% of Spanish wind farms have asked the TSO (REE) for authorization tests to provide adjustment services.

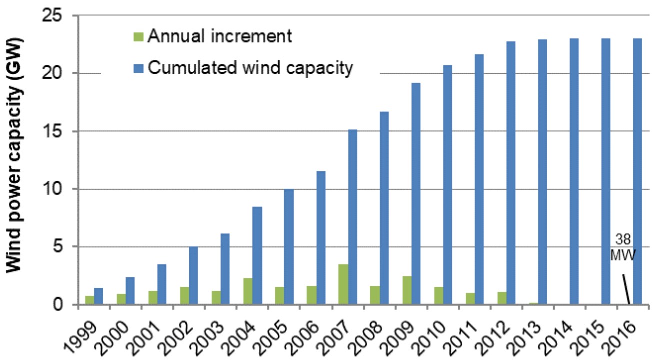

Figure 1. Annual and cumulative installed wind power capacity in Spain (Source AEE)

Repowering is anticipated in Spain: 12 GW of wind power capacity has been operating for more than 10 years—more than 3.5 GW are older than 15 years.

4.0 Impact of Wind Energy

According to the Spanish Wind Energy Association (AEE), the price of electricity in 2016 would have been 28% higher—around 15.26 EUR/MWh (12.90 USD/MWh)—without the 23.0 GW of wind power capacity deployed in Spain.

4.1 Environmental impact

Despite a slight increase in the electrical power demand during 2016, REE reports indicate that CO_2 emissions from the Spanish power generation sector decreased by 18%. In 2016, 47.7 TWh of wind-generated electricity avoided approximately 11.54 million tons of CO_2, reducing the Spain energy-related annual CO_2 emissions by 3.5%. Nearly 1,000 MW of coal-based power plants were decommissioned in 2016.

4.2 Economic benefits

The Spanish wind sector employs 22,468 people annually. More than 200 companies work in Spain, often focusing on exports due to a lack of national deployment. The sector accounts for 1% of total exports, around 2.574 billion EUR (2.710 billion USD) in 2016—12% lower than in 2015.

4.3 Industry development

In April, wind turbine manufacturers Nordex (Germany) and Acciona Wind Power (Spain) completed a merger process.

In June, the German Siemens Wind Turbines and the Spanish WEC`s manufacturer Gamesa Corp. Tecnologica also merged. The global headquarters and land-based division will be in Spain and anticipate total revenues around 230 million EUR (242 million USD).

While Spain has only installed one 5-MW offshore wind turbine to date, there are several Spanish offshore component suppliers:

Table 1. Key National Statistics 2016: Spain

Total (net) installed wind power capacity*	23,026 MW
Total offshore capacity	5 MW
New wind power capacity installed	38 MW
Decommissioned capacity	0 MW
Total electrical energy output from wind	47.7 TWh
Wind-generated electricity as percent of national electricity demand	19.3%
Average national capacity factor	23.48%
Target (2020)	29.4 GW
National wind energy R&D budget	85.5 million EUR (90 million USD)

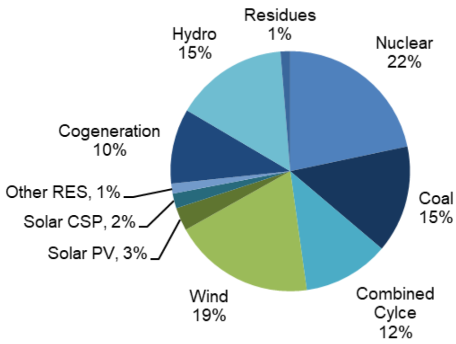

Figure 2. Sources of the 2016 power supply in Spain (Source: REE)

- Navantia shipyards supplied jacket foundations and built and installed offshore power substation platforms, projects worth 160 million EUR (168.48 million USD).
- Kicardine Offshore Wind Farm Ltd (KOWL) has chosen to use COBRA's floating semi-spar concrete substructure technology, instead of Principle Power's Windfloat as originally planned.
- In November, Iberdrola and Navantia signed a contract to construct the offshore wind farm electrical substation and 42 jackets for East Anglia 1 in the UK.
- Navantia-Windar will supply 5 spar-type floating foundations for 6 MW turbines for Hywind Scotland Ltd—the world's first commercial floating test park (Figure 3).

5.0 R,D&D Activities

5.1 National R,D&D priorities

The Spanish Government considers wind energy a national priority. R&D activities primarily focus on land-based applications: increasing O&M cost competitiveness, extension of life strategies for wind farms, optimized manufacturing process, etc. Offshore wind R&D activities are increasing, especially for floating components.

5.2 R&D budget

National investments in wind energy R&D amounted to 85.5 M EUR (90 million USD) in 2016. This budget is slightly higher than the previous years, and industry anticipates similar investments beyond 2017.

5.3 Research results

In 2016, the Spanish government continued the State Plan for Scientific and Technical Research and Innovation 2013–2016, following the 2011 Spanish Strategy for Science Technology and Innovation [7]. The Plan tries to align the R&I priorities with those set in the European Strategic Energy Technology Plan (SETPlan).

A general R&D call for proposals addressing societal challenges awarded two wind energy related topics in 2016: simulation and testing of traction kites for energy generation (University Carlos III Madrid UC3), and the development of an advanced control for the PMSG "Full converter" wind turbine with unbalanced harmonic distortion and servicing to frequency regulation (University of Basque Country).

Around 3.5 GW are used for adjusting the Spanish electrical system. Developers expect to increase the wind power capacity in balancing market up to 50% of total wind capacity.

Another call for collaborative public and private proposals awarded a combination of grants and loans to nine projects:

- New strategies for validating of wind turbines, **NABRAWIND** Technologies S.L.
- **PROTOS:** High productivity welding for offshore wind towers manufacturing, GRI Renewable Industries S.L.
- **AEROEXTREME:** Wind turbines for aggressive and extreme environments, GAMESA Innovation and technology S.L.
- **MHiRED:** Hybrid wind/solar mini-grids management based on energy storage systems or grid connected with synchronism in island operation, Optimal Renewable Systems S.L.
- **OFFCOAT:** Anti-corrosion system for wind towers used in marine environments, MUGAPE S.L.
- **ORPHEO:** Optimization of hybrid platforms for wind and wave energy, INGETEAM Service S.A.
- Safety control system for offshore wind turbines, Ingeteam Power Technology S.A.
- **SIMMULA:** System for predictive maintenance of wind turbines, Instituto Tecnológico y de Energias Renovables S.L. ITER research center
- **HVDC-AEOLUS** Advanced control system for offshore wind farm with network optimization, GREENPOWER Technologies S.L.

The Center for the Technological and Industrial Development (CDTI) coordinated an instrument to support innovative projects led by private companies. During 2016, one wind energy project was granted funding to develop automated scan cutting and welding wind towers gates.

Spain is involved with two offshore wind European Research Areas Networks (ERA-NET) projects. Three other projects were granted funding under DEMOWIND 1 (2015-2019):

- **WIP 10+:** A project to develop and demonstrate a fully-integrated floating offshore wind platform (Wind2Power) capable of holding twin 6-MW wind turbines and hosting additional functions due to its large size. Project partners include EnerOcean S.L. (Coord), Ingeteam Service, Ghenova Ingeniería S.L., TTI Tension Tech International Ltd, and PLOCAN.
- **XL Blade:** Three offshore industry leaders will design, validate, and deploy the world's largest offshore wind turbine blade (approaching 90 m) to reduce the overall cost of offshore wind energy. Project partners are Adwen Offshore S.L. (Coord), Gamesa Innovation and technology S.L., LM Windpower A/S, Romax Technology Limited, and ORE Catapult Development Services.
- **MD500 WIND:** A project to launch a new remotely-operated seafloor-based robot for submarine geotechnical site investigation for offshore wind projects by re-tooling a robotic general-purpose submarine drilling machine. Project partners are Enerocean S.L./ Ingeotest S.L. (Coord) and MG3 UK Limited.

Under DEMOWIND 2 (2016-2020), CDTI funded six Spanish entities participating in four projects and MINECO funded one entity to participate in a project. Spanish companies are participating in H2020 funded projects for qualification of innovative floating substructures for 10 MW wind turbines and water depths greater than 50 m (LIFES50+) and demonstration of a gravity-based offshore wind turbine foundation (DEMOGRAVI3). Three H2020 projects will be led by Spanish companies:

- **TELWIND:** Integrated telescopic tower and evolved spar floating substructure for low-cost deep offshore wind and the next generation of 10MW+ turbines (<TRL5), ESTEYCO SAP
- **ELISA/ELICAN:** Full-scale offshore prototype of a self-buoyant telescopic precast concrete foundation for crane-less installation of complete offshore wind turbines, ESTEYCO SAP
- **HPC4E:** High Performance Computing for Energy, the Barcelona Supercomputing Centre (BSC)

5.4 Test facilities and demonstration projects

The Canary Islands Oceanic Platform (PLOCAN) is a floating laboratory 2.5 km from shore for public R,D&I with easy access to deep waters. The BISCAY Marine Energy Platform S.A. (BIMEP) is a public research facility for testing marine energies with easy access to waves and wind for testing purposes. The near-shore facility has 50-90 m water depths and two 5-MW powerline connections.

5.5 Collaborative research

Spain will coordinate a three-year Small Wind Turbines Organization and Market Promotion (SWTOMP) project, under the ERANET LAC framework, with participants from the EU and Latin America.

Spain serves as operating agent for IEA Wind TCP Task 27: Small Wind Turbines in Highly Turbulent Sites and Task 31: Wakebench: Benchmarking Wind Farm Flow Models. Spain also participates in:

- Task 11: Base Technology Information Exchange
- Task 25: Power System with Large Amounts of Wind Power
- Task 30: OC5 Offshore Code Comparison Collaboration, Continuation with Correlation
- Task 34: Environmental Assessment and Monitoring
- Task 36: Forecasting for Wind Energy
- Task 37: Wind Energy Systems Engineering Integrated R, D&D

Figure 3. Boat loading process for the Hywind project floating foundations in Ferrol, Spain (Photo credit: Navantia-Windar)

Without the 23.0 GW of wind power capacity deployed in Spain, by 2016 the price of electricity would have been 28% higher, around 15.26 EUR/MWh (12.90 USD/MWh).

6.0 Next Term

Spain is well placed to take advantage of global opportunities in the wind energy sector, as evidenced by current export levels. Spanish manufactures have merged with other companies to reinforce the country's position in the market. Challenges include reducing costs for fixed-bottom offshore applications and developing viable floating offshore solutions for deep waters.

In Spain, most of the coastline available for wind energy has deep water. There are also enough available land-based resources to double the current wind power capacity. When the government provides a new regulatory framework, reduced uncertainty will help boost the domestic market to meet international commitments.

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Opening photo: Windy night in Spain (Photo credit: Gabriel González)

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Sweden

1.0 Introduction

In 2016, Sweden's new wind energy installations had a capacity of 605 MW (604 MW were installed in 2015). At the end of 2016, the total installed capicity was 6,422 MW from 3,335 wind turbines.

Sweden has a goal within the EU burden-sharing agreement of at least a 50% share of renewable energy in the total energy use by 2020. New ambitious targets were announced in 2016 for 100% renewable electricity production in 2040. The Swedish Energy Agency estimates that about 2.5 to 6 TWh of new renewable power capcity will need to be installed annually between 2030 and 2040 to reach that goal and, wind power could provide a large part of this capacity.

As the main wind power R,D&D funding agency in Sweden, the Swedish Energy Agency finances research conducted by universities and industries in several research programs. The overarching goals of R,D&D in wind power is to help Sweden reach targets and national objectives for a renewable energy system, to contribute to business development, and to increase jobs and exports.

2.0 National Objectives

According to the EU burden-sharing agreement, Sweden is required to achieve a renewable energy share of 49% by 2020. However, Sweden has increased this goal to a renewable energy share of at least 50% of the total energy use.

In 2016, the government, the Moderate Party, the Centre Party, and the Christian Democrats reached an agreement on Sweden's long-term energy policy. This agreement consists of a common roadmap for a controlled transition to an entirely renewable electricity system, with target as follows:

- By 2040, Sweden should achieve 100% renewable electricity production. This target is not a deadline for banning nuclear power, nor does it mean closing nuclear power plants through political decisions.
- By 2045, Sweden is to have no net emissions of greenhouse gases into the atmosphere and should thereafter achieve negative emissions.
- By 2030 an energy-efficiency target of 50% more efficient energy use compared with 2005. The target is expressed in terms of energy relatively to GDP.

2.1 Targets

Sweden has a technology-neutral market-based support system for renewable electricity production called the electricity certificate. Sweden and Norway have shared a common electricity certificates market since 2012, wherein certificates may be traded between borders.

Sweden has a stable wind power market of 600 MW/year and generated 12% of electricity from wind power in 2016.

The objective of the common certificates market is to increase the production of renewable electricity by 26.4 TWh by 2020, compared to 2012. This corresponds to approximately 10% of total electricity production in both countries—achieved principally through bio-power and wind power. In the Swedish energy policy agreement signed in 2016, the electricity certificate support scheme was extended to 2030 with an added ambition of 18 TWh.

2.2 Policies supporting development

The main incentive for renewables is the electricity certificate scheme, a market-based support system for renewable electricity production. The system came into force in 2003 with the intention to increase the production of renewable electricity and to decrease the cost of production. The work done in assessing areas of national interest for wind power can also be considered a "soft incentive."

In the electricity certificate scheme, the government awards electricity producers a certificate for each MWh produced from renewable resources. Only new power plants or plants which have undergone recent significant changes are entitled to certificates. Producers can then sell the certificates on an open market to electricity consumers. The demand for electricity certificates is

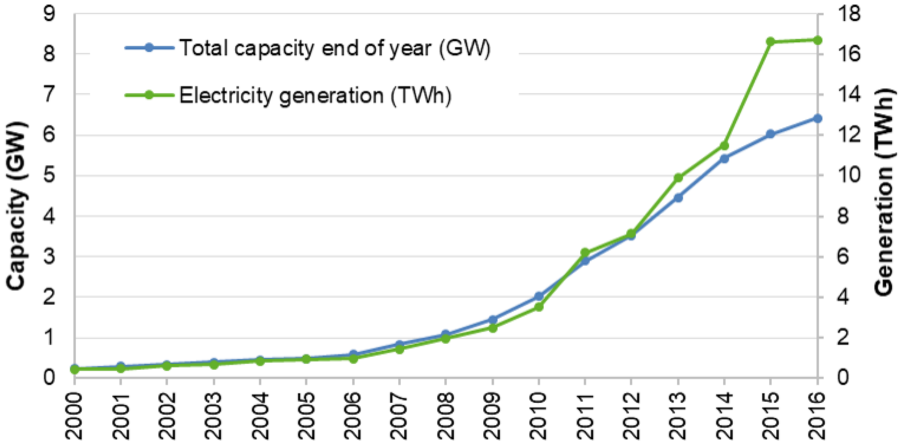

Figure 1. Installed wind power capacity in Sweden from 2000–2016

regulated by means of a quota which is set in proportion to total electricity use. The energy-intensive industry is however exempt from this requirement.

The price is determined freely on the market and varies with demand and supply. Renewable energy sources include wind, solar, wave, and geothermal, as well as some hydropower, biofuels, and peat in combined heat and power (CHP) plants. The main contributors are bio-power and wind power.

3.0 Implementation and Deployment

New wind energy installations in 2016 had a capacity of 605 MW, compared to the 604 MW installed in 2015. At the end of 2016, the total installed capacity was 6,422 MW from 3,335 wind turbines. The total electrical energy output from wind was 16.7 TWh.

Northern Sweden exhibits many areas with high potential for wind power; however, turbines in these areas face several challenges not seen in areas with warmer climates. As such, wind power in cold climates is gaining more interest. One such challenge is the risk of ice on the wind turbine blades, which reduces production and may result in falling ice. Reports from wind power operations in cold climates indicate that ice buildup on wind turbine blades can contribute to substantial production losses.

Wind turbines in such areas must be equipped with special cold climate packages, which may include special steel qualities in tower and nacelle structures and special types of oil and grease. It is also essential to equip blades with de-icing or anti-icing equipment. Swedish Energy Agency specifically provides funding to R,D&D projects to support the deployment of wind power in cold climates.

3.1 Matters affecting growth and work to remove barriers

The expansion of wind power in Sweden is mainly driven by the incentives within the electricity certificate system. Because of the price erosion of both electricity and certificates in recent years, only the most profitable sites can be considered today for new wind farms.

4.0 Impact of Wind Energy

The Swedish energy policy aims for social, economic, and ecological long-term sustainability of the energy system, while maintaining security of supply. This can be achieved via an active energy policy, incentives and research funding. Currently, CO_2 emissions related to electricity production are relatively low, since hydro, nuclear, bio, and wind energy are the main contributors.

5.0 R,D&D Activities

5.1 National R,D&D priorities

As the main funding agency within wind power R,D&D in Sweden, the Swedish Energy Agency adopted a strategy in 2016 with three prioritized areas for wind power: wind in Swedish conditions, sustainability, and integration in the energy system. Wind in Swedish conditions refers to the agency's support for installation

Table 1. Key National Statistics 2016: Sweden

Total (net) installed wind power capacity	6,422 MW
Total offshore capacity	190 MW
New wind power capacity installed	605 MW
Decommissioned capacity	2 MW
Total electrical energy output from wind	16.7 TWh
Wind-generated electricity as percent of national electricity demand	12.2%
Average national capacity factor	30%
Target	N/A
National wind energy R&D budget	60 million SEK*

*Includes only the Swedish Energy Agency R&D budget, the main founding agency of wind power R&D in Sweden.

Sweden announced new ambitious targets in 2016 for 100% renewable electricity production by 2040.

activities and operation of wind turbines in cold climates, forested environments, and the Baltic Sea.

The overarching aim of R,D&D in wind power is to make contributions that help Sweden reach the target and national objectives for a renewable energy system (Section 2.0). Moreover, it should also contribute to business development in Sweden, creating jobs and increasing Swedish exports.

5.2 R&D budget

Four research programs carried out publicly-funded wind energy research in 2016: Vindforsk, Vindval, the SWPTC, and Wind power in cold climate [5]. All four programs were under the supervision of the Swedish Energy Agency [2–5].

The present period of Vindforsk runs from 2013–2017 with a total budget of 60 million SEK (6.2 million EUR; 6.6 million USD). The program is financed 50% by the Swedish Energy Agency and 50% by industry. Vindforsk is organized in three project packages: wind resource assessment and installation, operation and maintenance, and grid integration.

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 will run through 2018 with a budget of 27 million SEK (2.8 million EUR; 3.0 million USD). The research projects supported in Vindval relate to wind power's impact on reindeer, golden eagles, and marine life, as well as noise annoyance from wind turbines.

The SWPTC runs from 2010–2018. The program is financed by industry, some universities, and the Swedish Energy Agency, with a total budget of 96 million SEK (10.0 million EUR; 10.6 million USD). The center focuses on designing of an optimal wind turbine, which takes the interaction among all components into account. The SWPTC is organized into six theme groups:

- Power and control systems
- Turbine and wind load
- Mechanical power transmission and system optimization
- Offshore
- Maintenance and reliability
- Cold climates.

The program Wind power in cold climate runs from 2013–2016. The program is financed by the Swedish Energy Agency and has a total budget of 32 million SEK (3.3 million EUR; 3.5 million USD). The program focuses on removing barriers that arise from installing wind power in cold climates.

5.3 Collaborative research

In 2016, Swedish researchers participated in EU programs (ERA-NET PLUS New European Wind Atlas) and the Nordic Energy Research programs, as well as several IEA Wind TCP 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 29: Mexnext: Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models
- Task 31: WAKEBENCH: Benchmarking Wind Farm Flow Models
- Task 33: Chapter 13 Reliability Data: Standardizing Data Collection for Wind Turbine Reliability, Operation, and Maintenance Analyses
- Task 34—Working Together to Resolve Environmental Effects of Wind Energy (WREN)
- Task 36—Chapter 16 Forecasting for Wind Energy

6.0 Next Term

Much of the expected growth in wind generation capacity will be in forested areas and in the northern parts of Sweden. High wind potential, as estimated by Swedish wind mapping, has sparked interest in these regions. However, there is substantial uncertainty surrounding 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 hope to increase the knowledge in this area.

The research programs Vindval, Vindforsk, and the SWPTC will continue during 2017, and a new wind energy program starts in 2017. The SWPTC activities will continue developing wind turbines, as well as optimizing maintenance and production costs.

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Opening photo: Wind turbines supplying electricity to Sweden (Credit: Per Westergård)

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Switzerland

1.0 Introduction

By the end of 2016, Switzerland had 37 large wind turbines in operation with a total rated power of 75 MW. These turbines produced 110 GWh of electricity. In 2016, a net new capacity of 15 MW was installed. Since no turbines were built in 2014 and 2015, the 20% capacity increase in 2016 represents a success.

A cost-covering feed-in-tariff (FIT) for renewable energy has been implemented in Switzerland since 2009 [1]. This policy promoted wind energy and led to a boost of new wind energy projects. Financing is currently requested for an additional 3.490 TWh under the FIT scheme.

Switzerland has developed an ancillary industry for wind turbine manufacturers and planners, which acts mainly on an international level. A study estimates that the total turnover in 2010 was about 38.9 million EUR (41.0 million USD) and that the wind industry employed about 290 people [2].

Research activities are internationally cross-linked, mainly in the fields of cold climates, turbulent and remote sites, and social acceptance.

2.0 National Objectives

After the 2011 disaster at Fukushima, the Swiss government and parliament decided to decommission existing nuclear power plants at the end of their operational lifespan and not replace them. To ensure the security of electricity supply, the Federal Council is placing emphasis on increased energy savings through energy efficiency as well as and expanding hydropower and new renewable energies as part of its Energy Strategy 2050 [3].

2.1 National targets

Within the new energy strategy, an additional 22.6 TWh/yr is expected to come from renewable energy. Wind energy should contribute 4.3 TWh/yr to this target (with intermediate goals of 0.7 TWh in 2020 and 1.8 TWh in 2035).

Since the introduction of the FIT in 2009, projects with an estimated energy yield of 87 GWh are in operation and being supported under the scheme; additional projects with a potential energy yield of 1,950 GWh have been registered, and 1,525 GWh are on the waiting list.

2.2 Policies supporting development

The cost-covering FIT for renewable energy is Switzerland's most significant measure. Renewable resources include hydropower (up to 10 MW), photovoltaics, wind energy, geothermal energy, and biomass.

The additional cost of the FIT is financed by a levy on electricity consumption. Following amendments of Swiss energy legislation, the levy was raised from 10.2 EUR/MWh (10.8 USD/MWh) to 12.1 EUR/MWh (12.7 USD/MWh) in the beginning of 2016, and then raised to 14.0 EUR/MWh (15.0 USD/MWh) in the middle of 2016—the maximum accepted under Swiss energy law. This leads to approximately 780 million CHF (727 million EUR; 765 million USD) of available funds each year, after deducting operating costs and funds reserved for annexed programs.

The current FIT for newly installed wind turbines is between 126–186 EUR/MWh (132–196 USD/MWh) [5]. Wind turbines built on locations 1,700 m above sea level or higher receive an altitude bonus of 23 EUR/MWh (24 USD/MWh) in addition to the standard retribution.

A Swiss Ornithological Institute study found that the bird collision rate was approximately 100 times lower than initially predicted. Although the wind park is known as a high migration site, collisions did not appear to peak during periods of high migration intensity.

3.0 Implementation and Deployment

3.1 Progress

Approximately 59% of Switzerland's overall electricity production comes from renewable sources, with hydropower by far the biggest contributor (95%). Wind power generation currently covers 0.2% of the Swiss electricity consumption.

In 2016, three new turbines were built, four turbines underwent

Figure 1. Repowering at Mont-Crosin, Switzerland (Photo credit: ©Suisse Eole)

a repowering—adding a total of 15 MW in the country. This 20% increase of capacity (from 60 MW to 75 MW) is a small breakthrough considering that no turbines were built the previous two years. Future projects that are already advanced in the planning procedures represent an additional 170 MW.

3.2 Operational details

In 2016, there was a wind farm inauguration at Gries pass; three Enercon E92 wind turbines of 2.3 MW were added to a pilot wind turbine in service since 2011. The three new wind turbines have a hub height of 85 m and a rotor diameter of 92 m.

The wind farm is about 2,500 m of altitude above the Gries dam. Weather conditions led to construction and transportation constraints at this high altitude. The energy generation monitoring on the pilot turbine shows that 60% of the wind farm production will occur in the winter months. The electricity produced at Gries pass will be retributed through the FIT scheme over 20 years.

The Mont-Crosin wind farm (the largest in Switzerland with 16 turbines) repowered four wind turbines in 2016. The new turbines are 3.3-MW Vestas V112s, and replace turbines installed in 2001 and 2004 (V52 and V66). The new turbines will increase the yearly wind-generated electricity of the farm from 50 GWh to 70 GWh. This was the second repowering at the Mont Crosin wind farm.

3.3 Matters affecting growth and work to remove barriers

Lengthy planning procedures are the greatest hindrance to Swiss wind energy growth. Stakeholders at different authority levels must first give their approval, as well as voters in the local population for a specific project. In general, the Swiss population is favorable to wind energy. However, the opposition is very well organized and manages to polarize the discussions on very specific topics, which slows down the planning procedures.

The new Energy Strategy 2050 is expected to ease planning procedures. In addition, one of the R&D focuses for the next three years is studying measures to accelerate planning procedures.

4.0 Impact of Wind Energy

4.1 Economic benefits

A study estimated that the total turnover in wind energy in Switzerland in 2010 was about 38.9 million EUR (41.0 million USD) and that the wind industry employed about 290 people [2]. Another from 2009 estimated the world-wide turnover of Swiss companies in wind energy will be 8.6 billion EUR (9.1 billion USD) by 2020, and that the wind industry will employ 32,000 employees worldwide [6].

4.2 Industry development

The Swiss industry is active in several wind energy fields:

- 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.)
- Components such as gearboxes (RUAG)

In 2016, Switzerland built three new turbines and repowered four turbines—totaling 15 MW net new wind power capacity. This 20% increase is a small breakthrough, considering that no turbines were built in 2014 and 2015.

5.0 R,D&D Activities

5.1 National R,D&D priorities

The work on wind energy in the Federal Energy Research Masterplan 2013–2016 focuses 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
- Increasing the acceptance of wind energy [7]

Pilot and demonstration projects are designed and implemented to increase market penetration of wind energy and close the gap between research activities and application in practice. In 2016, topics related to wind energy acceptance received significant attention (see 5.3 research results).

5.2 R&D budget

In 2016, the budget for wind energy related R&D and demonstration projects was approximately 620,300 EUR (653,176 USD). Within the national Swiss Energy program, approximately 1.1 million CHF (1.0 million EUR; 1.1 million USD) were allocated to the wind energy sector for information activities, quality assurance measures, and for the support of regional and communal planning authorities [8].

5.3 Research results

Low bird collision rate, not linked with migration intensity, is a major focus in Swiss wind energy research [9]. The mortality of breeding and migratory birds due to turbine collisions must be investigated for wind farm projects, as well as potential changes or loss of habitat.

To reduce the number of birds colliding with wind turbines during migration, Switzerland has discussed temporarily shutting down wind turbines when migration intensity is high. In order to define measures

Table 1. Key National Statistics 2016: Switzerland	
Total (net) installed wind power capacity	75 MW
Total offshore capacity	0 MW
New wind power capacity installed	15 MW
Decommissioned capacity	0 MW
Total electrical energy output from wind	0.110 TWh
Wind-generated electricity as percent of national electricity demand	0.2%
Average national capacity factor	NA
Target	4.3 TWh/yr
National wind energy R&D budget	1.6 million EUR; 1.7 million USD

Figure 2. Swiss wind farm overlooking Gries Glacier (Photo credit: Olivier Weiss, Swisswinds)

that can be integrated into the authorization procedures for wind power projects, it is essential to understand the relationship between the number of birds theoretically exposed to collisions and the number of birds which effectively collide.

The Swiss Ornithological Institute in Sempach combined a systematic carcass search study with simultaneously-conducted quantitative radar measurements using a radar device calibrated for bird detection. Between March and November 2015, researchers systematically searched the ground below the three 150-m high wind turbines in Le Peuchapatte in the Jura mountains for bird remains.

With 20 carcasses (no sensitive species) found in total, the results showed that the bird collision rate was approximately 100 times lower than initially predicted. Although the wind park is known as a high migration site, the carcass findings did not peak during periods of high migration intensity. The Swiss Ornithological Institute found no correlation between collision events and migration intensity at the height of the wind turbines. This confirms what other international studies showed: that migration intensity through wind farms is not a relevant issue in bird mortality. Shutting down the turbines during bird migration should be reconsidered, as high energy production losses would lead to limited bird mortality improvement.

Another area of interest is the impact of wind turbines on air navigation safety and network communication. In 2016, the regional authority, Canton Vaud, mandated Skyguide, a privileged partner of the Federal Office of Swiss Aviation, to investigate the potential impact of wind turbines on air navigation safety. The study covered ground installations that are essential to managing and monitoring air traffic: communication, navigation, and surveillance systems. It also covered the physical obstacle considerations that are part of the instrument flight procedures.

Along with geometry change possibilities such as relocating wind turbines, lowering turbine heights, raising minimal vectoring altitudes and cancellations, the assessment involved a surveillance radar mitigation solution called the track initiation inhibition zone. This feature avoids new traces from random radar echoes in a defined zone, for example, a zone in which obstacles like wind turbines might be erected. This option would grant conditional approval for several Swiss wind farm projects to move forward, as they are currently blocked because of air safety reasons.

A third topic that is particularly important in the Swiss context is the impact of wind turbines on microwave link systems. Given the very restricted regulation in Switzerland, mobile operators must densify their radio access network to guarantee a sufficient coverage. The Swiss topography and other resilient considerations results in a high probability of collocation of wind farms and microwave link systems. This issue has been addressed and a measurement project is being developed.

5.4 Collaborative research

Switzerland participated in the following IEA Wind TCP Tasks:

- Task 11 Base Technology Information Exchange
- Task 19 Wind Energy in Cold Climates
- Task 26 Cost of Wind Energy
- Task 28 Social Acceptance of Wind Energy Projects
- Task 31 WAKEBENCH: Benchmarking of Wind Farm Flow Models
- Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN)

6.0 Next Term

Approximately 170 MW of new wind power capacity is anticipated in the near future. The new energy research concept for 2017–2020 was elaborated in 2016 by the Swiss Federal Office of Energy. It focuses on three main topics:

- Performance optimization per turbine and farm: turbine optimization, control optimization, wind farm design
- Reduction of turbine downtimes: technical optimizations, icing protection, wind forecast, avifauna
- Acceptance: accelerating procedures and research between wind power and other fields, such as ornithology or noise research including stronger cooperation between federal offices and institutes

References:

Opening photo: Gries pass wind farm at 2,000 m, beside a Swiss pumped storage reservoir (Photo credit: Olivier Weiss, Swisswinds)

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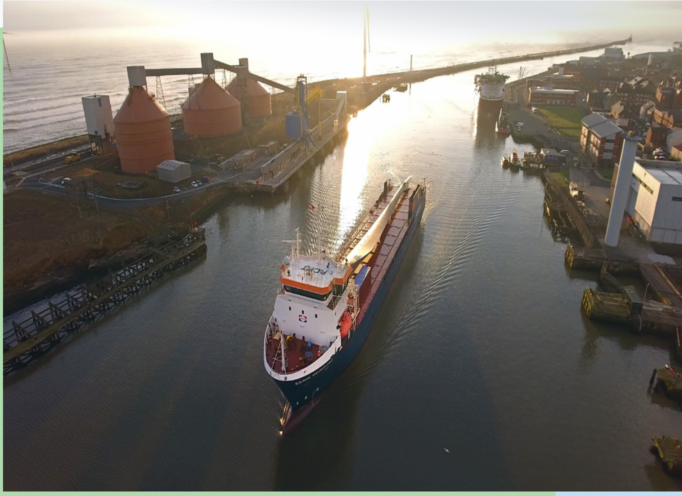
United Kingdom

1.0 Introduction

The United Kingdom had a successful year for wind energy in 2016; the offshore market continued to grow and the level of wind energy penetration in the grid remained over 10% despite lower than average wind speeds [1].

The remarkable cost reduction achieved by offshore wind has contributed to increased investor confidence in the public sector. Significant investments in manufacturing facilities have materialized, showing the confidence in the potential of the UK market's supply chain. The second Contract for Difference (CfD) auction round announced in 2016, will ensure continued deployment, although the lack of long-term visibility of new capacity reduces the certainty of future investments.

In 2016, the UK made significant progress in the deployment of higher-rated turbines, new test facilities, condition monitoring, and application of computational fluid dynamics to wind farm design, as well as floating wind technology.



2.0 National Objectives

The UK's renewable energy policy addresses the energy trilemma of security, affordability, and carbon reduction. From a low carbon perspective, this is driven by EU targets and the Paris Climate Agreement. The Levy Control Framework (LCF) manages affordability, controls the costs of all low-carbon support mechanisms paid for through consumers' energy bills, and sets an annual budget for projected costs of all low-carbon electricity levy-funded schemes until 2020–2021.

2.1 Targets

The Climate Change Act 2008 established a target for the UK to achieve an 80% reduction in greenhouse gases by 2050, compared to a 1990 baseline. This will be accomplished by setting five-yearly carbon budgets [2]. The UK Parliament approved the 5th Carbon Budget (2028–2032) in July 2016, following recommendations of the Committee on Climate Change (CCC) [3, 4].

The UK has a renewable energy target of 15% by 2020, as part of the EU's overall target of 20% renewables [5]. LCF provides an estimate of the capacity that is expected to be allocated. For offshore wind, the potential 2020 deployment is approximately 10 GW, dependent on a range of factors including cost reduction over time. For land-based wind, the potential 2020 deployment is up to 12 GW [6].

2.2 Policies supporting development

The implementation of the Electricity Market Reform is now complete, following the closure of the Renewables Obligation Certificate scheme and the introduction of the replacement competitive auction framework CfD.

In November 2016, the government announced the second CfD auction, opening in April 2017. This will allow bids from offshore wind projects up to a capacity of approximately 1.8 GW [7]. Land-based wind has not been included as an eligible technology for this round of CfD subsidies. As such, land-based site development will decrease significantly after all current development has been completed.

3.0 Implementation and Deployment

3.1 Progress

The UK continued to increase its land-based and offshore wind capacity throughout 2016. Land-based capacity increased 15% to 10.6 GW, reflecting the push to commission projects before the closure of the Renewables Obligation (RO) scheme. Offshore capacity remained at 5 GW, but there is almost 2 GW of capacity under construction. The growth of offshore wind is forecast to reach 10 GW of installed offshore wind capacity by 2020 [5].

Wind-generated electricity in the UK was responsible for 37.5 TWh in 2016, or 11.1% of the total electricity generation. This is slightly lower than 2015, reflecting the lower than average wind resource in the past year. Wind energy still achieved record power output, breaking the 10-GW mark on 7 December 2016.

3.2 Operational details

The annual Cost Reduction Monitoring Framework found that UK projects that made a final investment decision (FID) in 2015–2016 achieved a Levelized Cost of Energy (LCOE) around 97 GBP/MWh (114 EUR/MWh; 120 USD/MWh). This is a 32% reduction from the 142 GBP/

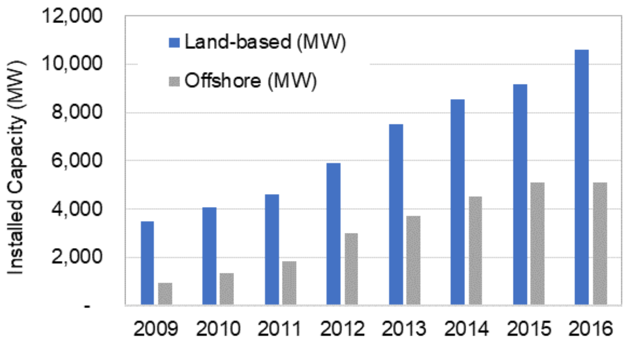


Figure 1. Installed wind power capacity in the UK from 2009–2016

United Kingdom

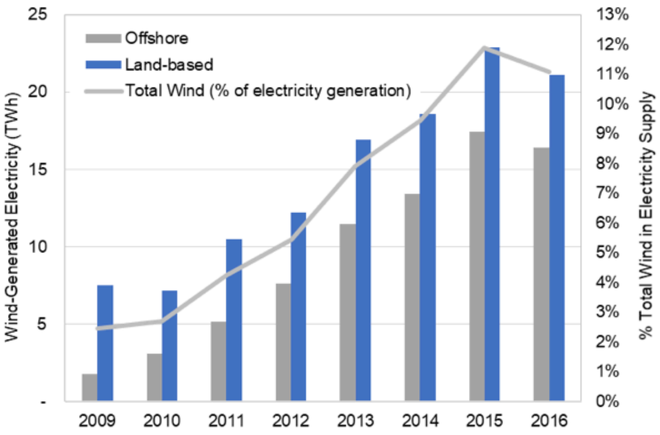


Figure 2. Electricity generated from wind in the UK from 2009–2016

MWh (166 EUR/MWh; 175 USD/MWh) projects reaching FID made in 2010–2011. This is the first year that the LCOE has been below 100 GBP/MWh (117 EUR/MWh; 123 USD/MWh), which is the target set by industry and government for projects reaching FID in 2020.

3.3 Matters affecting growth and work to remove barriers

The offshore wind sector welcomed the confirmation of the second CfD auction round, as it provides growth to 2020–2021. The absence of land-based wind from the auction eligibility reaffirms the government's reluctance to subsidize any new land-based wind due to concerns about visual impact and cost.

The government's delay in announcing a replacement of the LCF beyond 2020–2021 does not provide the long-term certainty of market growth that the supply chain needs to make significant investments.

4.0 Impact of Wind Energy

4.1 Environmental impact

Wind-generated electricity outperformed coal for the entirety of 2016, generating over 11% of the UK's electricity. This was the first time that wind consistently exceeded coal, which generated only 9% of electricity. Overall, one quarter of the UK's electricity came from renewable sources in 2016 [1].

4.2 Economic benefits

The past year has seen an increased focus on the level of UK content in offshore wind projects. The supply chain plans that were a requirement of the CfD process are now moving into implementation.

The 310 million GBP (363 million EUR; 382 million USD) investment in the Siemens Blade Manufacturing Plant in Hull has been realized. The facility opened in September 2016 and the first 75-m blades have emerged from the plant. The plant employs 700 people and recruitment for up to 1,000 jobs is anticipated to continue into 2017 as the site becomes fully operational [8].

In March 2017, ORE Catapult highlighted the economic benefits of a strong UK offshore wind industry [9, 10]. The UK economy is already reaping the rewards of a maturing offshore wind sector. Figures suggest that continued cost reduction, coupled with increasing amounts of UK content in projects being commissioned, will result in a significant increase in the economic return for the UK. Supporting offshore wind is cost-benefit neutral with a strike price of 105 GBP (123 EUR; 130 USD) and 30% UK content.

4.3 Industry development

Success stories in the UK supply chain include: JDR Cables winning contracts for array cables across Europe; Siemens Wind Power opening the Hull blade manufacturing facility; Babcock's success with substation topside manufacture; BiFab, Harland, and Wolfe winning contracts for jackets; and CS Wind expanding their capability to include offshore towers. The MHI Vestas Offshore Wind facility on the Isle of Wight also supplied the 80-m blades for the V164-8.0 MW Burbo Bank Extension project.

5.0 R,D&D Activities

The Engineering and Physical Sciences Research Council (EPSRC) operates the SUPERGEN Wind Hub to enhance academic, industrial, and policy linkages. The Hub's links to the leadership of the major EPSRC Doctoral Training Centers (DTCs) influences future research in the UK.

The scope of research covers three main headings: planning and consenting; design, manufacturing, and installation; and operation, maintenance, and decommissioning.

5.1 National R,D&D priorities

Innovate UK aims to help businesses innovate faster and more effectively, using its expertise, connections, and funding. Key priorities are:

- Offshore wind cost reduction to enable competitive generation with conventional forms by the mid-2020s
- Improvement in economic growth through innovation support and growing businesses
- Creation of opportunity for UK businesses to capture market share

5.2 R&D budget

Primary funding from Innovate UK comes from infrastructure systems calls, providing a budget of approximately 30 million GBP (35 million EUR; 37 million USD) annually. Offshore wind makes up approximately one-sixth of this budget. In 2016, Innovate UK committed 1,827,100 GBP (2,141,361 EUR; 2,252,814 USD)

Table 1. Key National Statistics 2016: United Kingdom

Total (net) installed wind power capacity	15,700 MW
Total offshore capacity	5,100 MW
New wind power capacity installed	1,400 MW
Decommissioned capacity	10 MW
Total electrical energy output from wind	37.51 TWh
Wind-generated electricity as percent of national electricity demand	11.1%
Average national capacity factor	28%
Target	20 GW by 2020
National wind energy R&D budget	N/A

in funding to offshore wind projects, with future funding levels anticipated to be similar.

The research element of SUPERGEN Wind Hub for 2016 is 241,725 GBP (283,302 EUR; 298,047 USD), while funding for innovative research projects totals 280,029 GBP (328,194 EUR; 345,276 USD).

Around 3,264,000 GBP (3,825,408 EUR; 4,024,512 USD) in funding was used to create Challenges projects in 2016. These projects focus on novel offshore foundation solutions, adaptive blade concepts, improved understanding of the flow field and aerodynamics, and wind energy carbon reduction. The Doctoral Training Centers receive an annual budget of 1,000,000 GBP (1,172,000 EUR; 1,233,000 USD).

The Offshore Renewable Energy Catapult is a key element of the offshore wind strategy of the UK government, and aims to facilitate the deployment of offshore renewable energy through research and innovation. ORE Catapult received over 10.0 million GBP (11.7 million EUR; 12.3 million USD) during 2016.

5.3 Research results

Key projects included a comprehensive review of how wind turbine supervisory control and data acquisition (SCADA) data is used for condition monitoring (Loughborough MAXFARM). Parametric CFD studies on the effect of wind turbine spacing on large wind turbine arrays have been conducted (Figure 3).

The OPTIMUS project ran from 2013–2016 and involved 13 partners from six countries working towards three main aims:

- Improving reliability within the wind power generation industry by delivering prognostic technology to evolve to predictive maintenance strategies
- Improving the efficiency of maintenance procedures and operational reliability of wind turbines
- Supporting the implementation of the European Wind Initiative of the SET-Plan (SEII)

To date, 13 specific exploitable results have been identified with six improvements classed as significant and eight new developments.

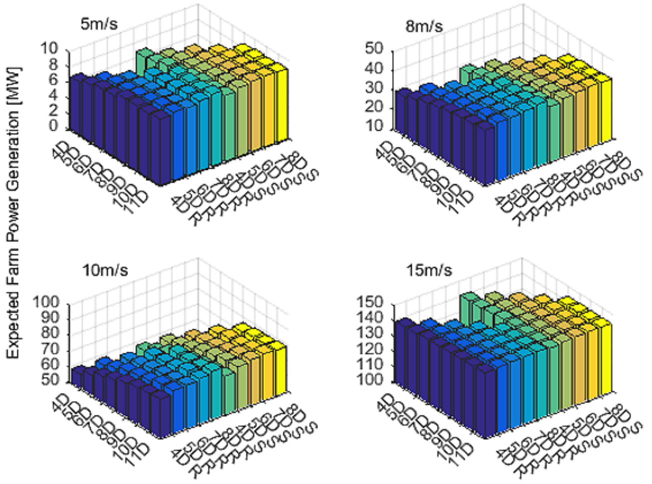


Figure 3. Simulated power output from a hypothetical offshore wind farm of 40 3.6-MW wind turbines as a function of row/column spacing and for regular (R) and staggered (S) layouts [11].

Market potential of condition monitoring technology: a cost-effective condition monitoring technique is essential to increase the availability of large wind turbines. Zigoorat Ltd has developed a novel technology, which is distinguished by both its capability in processing non-stationary/non-linear signals and its computational algorithm. It has substantially greater fault detection precision as well as easy installation mechanism.

Novel Wind Energy Concept at Strathclyde University with the Innwind.EU project: This novel 20-MW concept consists of 45 x 444-kW rotors. The multi rotor system technology could result in LCOE reduction of 30% (Figure 4).

5.4 Test facilities & demonstration projects

The UK leads on the development and demonstration of floating offshore wind. This includes upgrading testing facilities, consenting of pre-commercial floating wind farms, and developing policy recommendations.

- The Wave Hub demonstration site has been upgraded. The development of floating wind parks Hywind Scotland, Kincardine Offshore Windfarm, and Dounreay Trì has continued.
- Win Win JIP has begun exploring the feasibility of wind-powered water injection oil.
- The Levenmouth Turbine is now fully operational and accessible for use for R&D.
- The North Sea Logistics' Pivoting Deck Vessel prototype will demonstrate a reduction in turbine downtime. The design was a 2011 finalist in the Carbon Trust's Offshore Wind Accelerator Access competition.
- The Wake Anemometry project is constructing a wake monitoring system to test alongside commercial laser-based systems. The expected outcome is a field demonstrator showing the benefits of wake anemometry.

5.5 Collaborative research

The IEA Wind TCP sponsors cooperative research tasks with UK engagement including:

- Task 26 Cost of Wind Energy
- Task 32 LIDAR: Lidar Systems for Wind Energy Deployment
- Task 33 Reliability Data: Standardizing Data Collection for Wind Turbine Reliability, Operation, and Maintenance Analyses
- Task 36 Forecasting for Wind Energy
- Task 37 Wind Energy Systems Engineering: Integrated Research, Design, and Development.
- Contributions to Task 30 Offshore Code Comparison Collaboration, Continued, with Corrleation (OC5)
- Other collaborations include work on the Validation of Frandsen Turbulence Intensity Model and Large Wind Farm Models project, INNWIND, WINDTRUST, Lifes 50+, IRPWind, and the Marie Curie AWESOME initiative

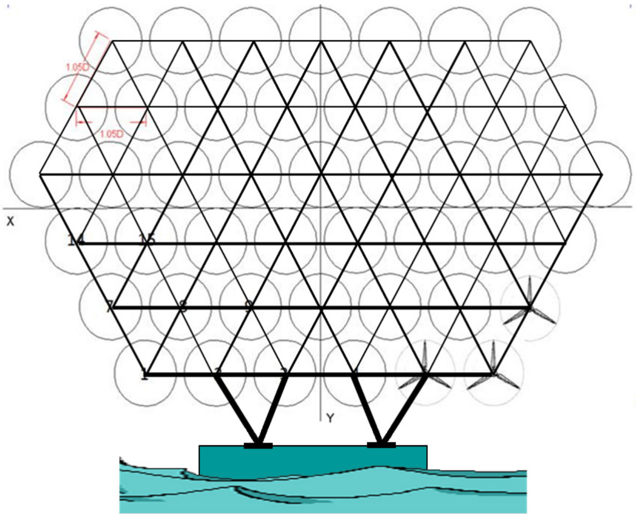


Figure 4. Multi rotor system concept. (Figure CreditLStrathclyde, Innwind.EU)

6.0 Next Term

Innovate UK R&D activities are expected to continue with an investment approach closely mirroring the 2016 model. For example, one project involves constructing a bespoke blade erosion test rig to develop and test the next generation of repair solutions. Other future UK projects include:

- The Offshore Wind Innovation Hub, which will synthesize the industry's priorities, create and maintain an agreed roadmap for tackling the key technology challenges, signpost funding. opportunities, provide a common 'front-door' for UK companies to become involved in projects and engage with international programs.
- Compact High Efficiency Generator, which aims to advance the state of the art in wind turbine generator technology by reducing the cost of the turbine and increasing efficiency.
- XL Blade, which hopes to reduce offshore wind CoE by merging the technological leadership of three industry leaders to design, validate and deploy the world's largest turbine blade.
- FSFOUND, which uses innovative design in Float and Sink (self-installing) Gravity Based Foundation to reduce the LCOE
- Offshore Demonstration Blade, which plans to reduce the CoE of offshore wind by demonstrating a set of blade technologies aimed at increasing the rotor energy performance.
- SPOWTT, which involves development of a decision support tool to benefit Crew Transfer Vessel use.

References:

Opening photo: One of the world's longest offshore wind turbine blades arriving at the Offshore Renewable Energy Catapult's testing facilities in Blyth, Northumberland. The 88-m blade will tested at ORE Catapult's world-leading blade-test facility as part of the XL Blade project (Photo credit: ORE Catapult).

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United States

1.0 Introduction

The U.S. wind industry achieved near-record growth in 2016, as the renewable energy Production Tax Credit (PTC) was renewed in December 2015 after having expired in January 2015. The PTC is an inflation-adjusted per-kilowatt-hour tax credit for electricity generated by qualifying facilities [1]. The extension included a phase-down approach for wind projects commencing construction after 31 December 2016, providing an incentive to start construction on new wind projects in 2016. Wind power generating capacity now exceeds conventional hydropower capacity in the United States [2].

The U.S. wind industry also embarked on a new era, as the first offshore wind facility—the 30-MW Block Island wind farm, located off the coast of Rhode Island—began commercial operation. A joint report of the U.S. Department of Energy (DOE) and the U.S. Department of the Interior, the *National Offshore Wind Strategy*, found a technical resource potential of more than 2 TW of offshore wind capacity, capable of generating 7,200 TWh of wind power per year [3]. A DOE-funded report on distributed wind also found a significant addressable resource potential, with 3 TW of capacity capable of generating 4,400 TWh of wind power, greater than current U.S. power consumption [4].

2.0 National Objectives

2.1 Targets

DOE aims to reduce the cost of utility-scale, land-based wind power to 0.052 USD/kWh (0.049 EUR/kWh), without incentives, by 2020, and to 0.031 USD/kWh (0.029 EUR/kWh) by 2030. The cost target for fixed-bottom offshore wind power is 0.149 USD/kWh (0.142 EUR/kWh) by 2020 and 0.093 USD/kWh (0.088 EUR/ kWh) by 2030 [5]. These cost targets are essential for enabling a greatly expanded level of deployment in every U.S. state and achieving high levels of wind energy penetration on the U.S. power grid.

Although the United States has no specific deployment goals, DOE has performed a technical examination of the feasibility of achieving rapid growth in the U.S. wind industry. DOE's Wind Vision report examines a scenario trajectory of supplying 10% of the nation's electrical demand by 2020, 20% by 2030, and 35% by 2050 [6]. The report found that these goals could be met by reducing wind power costs, expanding the developable areas for wind power, and deploying wind in ways that increase economic value for the nation, including support for U.S. jobs and manufacturing.

2.2 Policies supporting development

The inflation-adjusted PTC for wind power was 0.023 USD/kWh (0.022 EUR/kWh) in 2016. However, the wind power PTC will gradually phase down over the next three years, dropping 20% per year based on when the facilities commenced construction. Wind facilities built after 2019 will earn no PTC [1].

The federal Investment Tax Credit (ITC) for small wind power (≤100 kW) expired in 2016. The ITC for large wind power was 30% in 2016, but like the PTC, it will phase down by 20% per year [7]. In contrast, state-based renewable portfolio standards (RPSs), which set requirements for the use of renewable energy, are now in place in 29 states, and some states are making their RPSs more aggressive. In addition, a wide variety of tax benefits, grants, rebates, financing options, and special tariffs are available at the state and local levels [8, 9].

3.0 Implementation and Deployment

Of the 8,203 MW installed by the U.S. wind industry in 2016, Texas installed the most (2,611 MW), followed by Oklahoma (1,462 MW), Iowa (707 MW), Kansas (687 MW), and North Dakota (603 MW). Cumulatively, Oklahoma surpassed California and now is the third-ranked state with more than 6,600 MW of installed capacity [10].

3.1 Progress

Although California once dominated U.S. wind power capacity, Texas and Iowa are now the leading states for wind power, with 20,320 MW and 6,911 MW of installed capacity, respectively [10].

The growth of U.S. wind power in the interior region is demonstrated by the percentage of wind power used to meet each state's electrical needs. In 2016, five central states—Iowa, Kansas, North Dakota, Oklahoma, and South Dakota—sourced more than 20% of their electricity from wind power [10]. The U.S. wind industry invested more than 14.1 billion USD (13.4 billion EUR) in new turbines in 2016, bringing the total operating fleet to approximately 53,343 turbines [10].

3.2 Matters affecting growth and work to remove barriers

The resolution of a phase down of the PTC spurred growth in the U.S. wind industry in the fourth quarter of 2016 (Figure 1). However, with the Clean Power Plan under a stay, uncertainty remains as to whether there will be additional federal incentives for wind power as a carbon-free energy source [11].

An additional factor affecting wind power expansion is access to transmission. In the United States, most wind resources are located far from the load centers that they could serve, sometimes requiring project developers to also develop transmission resources. For instance, the largest proposed wind farm in North America, the 3,000 MW Chokecherry and Sierra Madre Wind Energy Project in Wyoming, aims to deliver its power to utilities in Southern California [12]. To

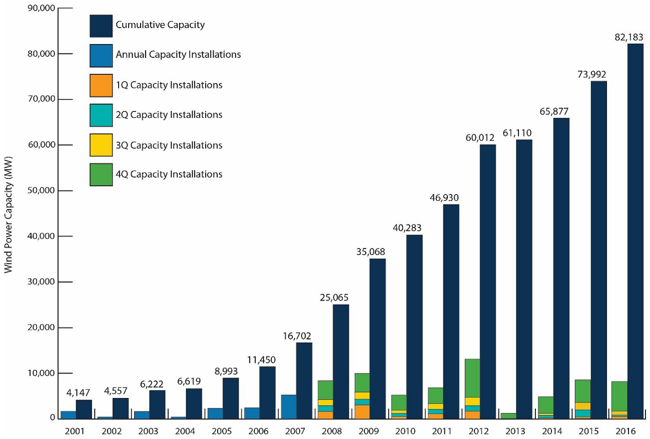

Figure 1. U.S. wind power capacity and generation growth from 2001 through 2016 (Graphic credit: American Wind Energy Association [9])

do so will require a 730-mile transmission line, the TransWest Express Transmission Project, which will run from Wyoming, through Utah, and into southern Nevada. The project will take three years to build at an estimated cost of 3 billion USD (2.85 billion EUR) [13]. In December 2016, the Bureau of Land Management (BLM), part of the U.S. Department of the Interior, approved the right-of-way for the project [14].

4.0 Impact of Wind Energy

4.1 Environmental impact

Wind energy greatly reduces a variety of air pollutants, including smog-causing sulfur dioxide (SO_2) and nitrogen oxides (NO_x), helping to lower the rate of asthma and other respiratory issues. U.S. wind generation in 2016 displaced an estimated 178,000 metric tons of SO_2 and 110,000 metric tons of NO_x. It also reduced water consumption at existing power plants by about 87 billion gallons [10].

The United States is also working to minimize the impacts of wind power on wildlife through collaborations between the wind industry and environmental organizations, such as the Bats and Wind Energy Cooperative. In 2016, DOE-funded researchers completed a multiyear study to reveal where and when bats fly offshore, and researchers worked to develop and validate the effectiveness of acoustic deterrents to warn bats away from wind turbines [15]. DOE also awarded more than 3 million USD (2.85 billion EUR) to six projects that will advance technical solutions to minimize eagle mortality at wind farms [16].

The United States leads IEA Wind TCP Task 34 Working Together to Resolve the Environmental Effects of Wind Energy (WREN), which has worked to expand the Tethys database to provide a wide range of information on environmental research resources on land-based, as well as offshore, wind [17]. The Bureau of Ocean Energy Management initiated their Real-time Opportunity for Development Environmental Observations effort, collecting data on environmental variables to help fill data gaps.

4.2 Economic benefits

U.S. wind has an annual economic benefit of about 20 billion USD (19 billion EUR) for the U.S. economy [18]. The U.S. wind industry supports about 102,000 domestic jobs, more than coal, natural gas, nuclear, or hydroelectric power plants [10]. The U.S. Bureau of Labor Statistics estimates that the demand for wind turbine technicians will grow 108% over the next decade, making it America's fastest-growing job [19].

4.3 Industry development

Today, more than 500 U.S. factories across 41 states build wind turbines and the parts for them [10]. Many of these jobs are going to former heavy-industry Midwestern states, bringing new jobs to the places where they are needed most. Every U.S. state has either a wind farm or a wind manufacturing facility. In fact, even though the U.S. Southeast is largely lacking in utility-scale wind farms, it hosts more than 100 wind component factories [20].

5.0 R,D&D Activities

5.1 National R,D&D priorities

DOE's Atmosphere to Electrons initiative continues to advance the understanding of the complex physics governing wind flow into and through wind power plants to optimize wind plant design, siting, and operations [21]. Over the next four years, DOE and its national laboratories will be working to model complex and turbulent flow of wind through large wind power plants as part of DOE's Exascale Computing Project, which is gearing up U.S. computational capabilities to leverage the next generation of supercomputers [22].

DOE aims to enable a U.S. offshore wind industry by investing in the development and demonstration of offshore wind technologies and refining the technologies employed by domestic wind technology manufacturers. DOE will also facilitate environmentally responsible

Table 1. Key National Statistics 2016: United States [10]

Total (net) installed wind power capacity	82,143 MW
Total offshore capacity	30 MW
New wind power capacity installed	8,203 MW
Decommissioned capacity	48 MW
Total electrical energy output from wind	226.5 TWh
Wind-generated electricity as percent of national electricity demand	5.5%
Average national capacity factor	35%
Target	Reduce the levelized cost of energy (LCOE) for utility-scale, land-based wind power to 0.05 USD/kWh (0.048 EUR/kWh) without incentives by 2020 and 0.031 USD/kWh (0.029 EUR/kWh) by 2030*; reduce the LCOE of fixed-bottom offshore wind power to 0.10 USD/kWh (0.095 EUR/kWh) by 2030 [5]
National wind energy R&D budget	95.45 million USD (90.68 million EUR)

*Note: This levelized cost of energy was calculated using a reference wind site of 7.25 m/s at 50 m, 7% real discount rate, 20-year plant life, and market-average installed capital expenditures for fiscal year 2014.

The U.S. wind industry supports more than 100,000 domestic jobs, more than coal, natural gas, nuclear, or hydroelectric power plants.

wind deployment through multiyear R,D&D efforts to overcome permitting challenges in the United States [23].

DOE is also investing in U.S. manufacturing competitiveness by applying advanced manufacturing techniques to wind turbine components and tooling. A specific example is an investigation by DOE's Oak Ridge National Laboratory of the use of 3-D printing to manufacture wind turbine blade molds [24]. Advanced manufacturing enables rapid prototyping, which can facilitate cost-competitive domestic products.

5.2 Research results

DOE's research results will help to break down barriers to wind energy on many fronts. The National Renewable Energy Laboratory (NREL) released version 8.15 of the lab's FAST modeling program (FAST v8), an open-source, multiphysics engineering software tool used to design and analyze wind turbines. FAST v8 is also a modular platform for creating, testing, and demonstrating new modeling and analysis capabilities [25].

Meanwhile, NREL researchers completed successful testing of an advanced drivetrain designed to achieve greater reliability through a simplified gearbox, a permanent-magnet generator, and a high-efficiency power converter [26]. In addition, researchers from DOE's Argonne National Laboratory have successfully replicated the leading cause of wind turbine gearbox failures, known as white-etching cracks or axial cracks—a problem that has plagued the wind industry for years [27].

Offshore wind presents new resource characterization challenges that DOE's Pacific Northwest National Laboratory (PNNL) is trying to address with lidar buoys. The buoys are packed with high-tech instruments to measure wind speed at multiple heights, air and sea-surface temperature, barometric pressure, relative humidity, wave height and period, and water conductivity. A buoy deployed off Virginia Beach (see Figure 2) yielded useful information about data quality and also revealed that the United States experiences more low-level jets of wind than European offshore environments [28].

5.3 Test facilities and demonstration projects

In 2016, DOE's Sandia National Laboratories finished heavily modifying a Vestas V27 turbine at the Scaled Wind Farm Test Facility in Lubbock, Texas, and successfully remounted the rotor onto the turbine [29]. The facility is the focus of a joint experiment conducted by Sandia and NREL to study the use of wind farm controls to mitigate the impact of wind turbine wakes on wind farm performance.

Under the second phase of DOE's Wind Forecast Improvement Project, researchers at PNNL and the National Oceanic and Atmospheric Administration added three new radar wind profilers at 150-mile intervals along the coast of Oregon and Washington [30]. These profilers project continuous radio signals nearly five miles into the atmosphere (Figure 3). By measuring changes in the radio waves caused by air movement, researchers can determine the speed and direction of oncoming wind patterns. Each profiler site also includes a radio acoustic sounding system to measure temperature changes.

DOE's Wind Energy Facilities book lists all wind test facilities that are available for industry use [31].

5.4 Collaborative research

U.S. representatives participated in research conducted for all but one of the IEA Wind TCP tasks in 2016. U.S. wind stakeholders coordinate with many U.S. departments and agencies through formal and informal relationships, as well as engagement with international stakeholders through IEA Wind TCP, the International Electrotechnical Commission, and other partnerships.

Examples of research conducted through U.S. interagency and international coordination include radar mitigation, wind power plant optimization, technology transfer, market barrier mitigation, and grid integration.

6.0 Next Term

The United States expects a continued boost in growth as wind power plant developers aim to bring their facilities online before another year of PTC phase-downs. Wind energy will also grow thanks to expanded transmission capacity, particularly in west Texas. There are now 10,432 MW under construction and 7,913 MW in advanced development, for a combined 18,344 MW of wind capacity underway [10]. A recent Navigant report projects U.S. wind growth of 8–10 GW/yr through 2020, bringing total incremental capacity in 2020 of more than 35 GW and increasing employment to 248,000 jobs, with an economic impact of 24 billion USD (22.8 billion EUR) [18].

Figure 2. Lidar buoys like this one hold an array of advanced research equipment that can assess the energy potential of offshore wind sites and accelerate permitting. (Photo credit: Pacific Northwest National Laboratory)

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Opening photo: Deepwater Wind's 30-MW Block Island Wind Farm, the first offshore wind farm in the United States, finished construction in 2016 (Photo credit: Dennis Schroeder, NREL)

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Figure 3. One of the new radar profilers installed along the west coast (Photo credit: Pacific Northwest National Laboratory)

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Appendix A

Contracting Parties and the Executive Committee of the IEA Wind TCP

The Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems—also known as the IEA Wind Technology Collaboration Programme (IEA Wind TCP)— operates under the auspices of the International Energy Agency (IEA). It 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) [1].

National governments and international organizations agree to participate in the IEA Wind TCP (formerly referred to as the IEA Wind Implementing Agreement) [2]. Since it began in 1977, participants have developed and deployed 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 TCP research tasks.

By joining, a contracting party's participating 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 (listed in Appendix B) about ways to participate in the IEA Wind TCP research tasks. The most current contact list of IEA Wind TCP members is available at www.ieawind.org.

Table 1. Contracting Parties to IEA Wind TCP in 2016

Country/Sponsor Member	Contracting Party to the IEA Wind 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	European Commission
Finland	The Finnish Funding Agency for Technology and Innovation (TEKES)
France	Government of France
Germany	Federal Ministry for Economic Affairs and Energy (BMWi)
Greece	Center of Renewable Energy Sources (CRES)
Ireland	Sustainable Energy Authority of Ireland (SEAI)
Italy	1) Ricerca sul Sistema Energetico (RSE S.p.A.) 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	Centro Mexicano de Innovación en Energía Eólica (CEMIE Eólico)
Netherlands	The Netherlands Enterprise Agency
Norway	1) The Norwegian Water Resources and Energy Directorate (NVE) 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	The U.S. Department of Energy
WindEurope (Sponsor)	WindEurope

Appendix A

Figure 1. ExCo 77 in Lisbon, Portugal

The 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, typically a government department or agency. However, 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 TCP as sponsor members.

The ExCo meets twice each year to exchange information on the member R,R&D programs, 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 the annual report and maintenance of the IEA Wind TCP website.

Officers

In 2016, Ingancio Marti (United Kingdom) served as chair; Stephan Barth (Germany), John McCann (Ireland), and Brian Smith (United States) served as vice chairs. The chair and vice chairs were re-elected to serve in 2017.

Participants

In 2016, there were several personnel changes among the members and alternate members representing their organizations (See Appendix B: IEA Wind TCP Executive Committee 2016). For the latest and most complete ExCo member contact information, visit www.ieawind.org. The sponsor member European Wind Energy Association was renamed to WindEurope and the contracting party for México changed to the Centro Mexicano de Innovación en Energía Eólica (CEMIE Eólico). All countries with active interest in wind energy are welcome to contact the Chair or Secretary by email at secretariat@ieawind.org and explore participation options.

Meetings

The ExCo met twice in 2016 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 deployment activity reports 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 77th ExCo meeting was hosted by the Laboratorio Nacional de Energia e Geologia, I.P. (LNEG). The meeting was held in Lisbon, Portugal, on 10–12 May 2016. The 36 participants included ExCo members or alternates from 19 participating countries and sponsor members and an observer from Ireland. Presentations were given about all 15 active research tasks. The Common Fund audit report for 2015 was approved. The hosts sponsored technical tours to the WindFloat floating Wind turbine in Aguçadoura near Oporto and the EDP Renewables wind dispatch central and control room.

The 78th ExCo meeting was cohosted by the European Commission and WindEurpoe. The meeting was held in Brussels, Belgium on 30 November2 December 2016. The 39 participants included ExCo Members or Alternates from 19 participating countries and sponsors; observers from the IEA Secretariat, Ireland, Japan, Mexico, and WindEurpoe also participated. The Common Fund budget for 2017 was approved. The hosts sponsored technical tour to a Storm wind park near Meer (near the Dutch border).

Decisions, Publications, and Outreach

In 2016, the IEA Wind TCP ExCo approved one new research task, Task 39 Quiet Wind Turbine Technologies, which will formally begin in 2017. Task 33 on reliability concluded at the end of 2016 with the publication of *Recommended Practice 17 Wind Farm Data Collection and Reliability Assessment for O&M Optimization* in April 2017.

The ExCo approved extending Task 27 Small Wind Turbines in High Turbulence Sites, Task 28 Social Acceptance of Wind Energy Projects, and Task 34 WREN – Working Together to Resolve Environmental Effects of Wind Energy. The ExCo also approved work plans for Task 34 WREN and Task 36 Forecasting for Wind Energy. The ExCo approved a short-term extension with no additional funding for Task 35 Full-Size, Ground Testing of Wind Turbines and Their Components so the task could complete their reporting requirements.

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 performed planning, communications, and outreach activities between ExCo meetings. One such activity is providing support to IEA Paris initiatives. For example, ExCo members attended the following events: the IEA Bali Clean Energy Forum in February 2016, Bali; the IEA Renewable Energy Working Party (REWP) 69th Meeting in March 2016, Paris; the IEA Flexibility Bioenergy Workshop in June 2016, Brussels; and the IEA "Well Below 2 Degree Scenarios" Workshop in June 2016, Paris.

Annual Reports

Each year, the IEA Wind TCP issues a report on its activities and those of its member countries and organizations. The *IEA Wind TCP 2015*

Table 2. Active IEA Wind TCP Research Tasks

Task #	Task Name	Operating Agent	No of Participating Countries in 2016
11	Base Technology Information Exchange	Vattenfall, Sweden (1987–2008); CENER, Spain (2009–2012; 2013–2014; 2015–2016); Planair, Switzerland (2017–2018)	15
19	Wind Energy in Cold Climates	Technical Research Centre of Finland (VTT), Finland (2001–2011; 2012–2015; 2016–2018)	11
25	Design and Operation of Power Systems with Large Amounts of Wind Power	Technical Research Centre of Finland (VTT), Finland (2005–2011; 2012–2014; 2015–2017)	18
26	Cost of Wind Energy	National Renewable Energy Laboratory (NREL), United States (2008–2011; 2013–2015; 2015–2018)	9
27	Small Wind Turbines in High Turbulence Sites	CIEMAT, Spain (2012–2016)	8
28	Social Acceptance of Wind Energy Projects	ENCO Energie-Consulting AG, Switzerland (2007–2011; 2012–2015), IPC, Ireland (2016–2019)	6
29	Mexnext: Analysis of Wind Tunnel Measurements and Improvement Aerodynamic Models	ECN, the Netherlands (2012–2014; 2015–2017)	10
30	OC3/OC4/OC5: Offshore Code Comparison Collaborative Continuation with Correlation	NREL, the United States, and Fraunhofer Institute for Wind Energy and Energy System Technology (IWES), Germany (2010–2013; 2014–2017)	13
31	WAKEBENCH: Benchmarking of Wind Farm Flow Models	CENER, Spain, and NREL, the United States (2011–2014; 2015–2017)	11
32	LIDAR: Wind Lidar Systems for Wind Energy Deployment	ForWind Centre for Wind Energy Research, Germany (2012–2015); Stuttgart Wind Energy (SWE), University of Stuttgart, Germany (2016–2018)	17
33	Reliability Data: Standardising Data Collection for Wind Turbine Reliability and Operation and Maintenance Analyses	Fraunhofer IWES, Germany (2012–2016)	11
34	Working Together to Resolve Environmental Effects of Wind Energy (WREN)	NREL, the United States (2013–2016; 2016–2019)	10
35	Full-Size Ground Testing of Wind Turbines and Components	Aachen University RWTH, Germany (2013–2016)	5
36	Forecasting for Wind Energy	DTU Wind Energy, Risø, Denmark (2015–2018)	13
37	Wind Energy Systems Engineering: Integrated Research, Design, and Development	NREL, the United States (2015–2018)	7
39	Quiet Wind Turbine Technologies	Approved in principle at the 78th meeting of the IEA Wind TCP Executive Committee (2017–2020)	

Annual Report was published in August 2016 and 1,100 copies were printed and distributed to member organizations. Press releases were issued with links to the electronic version on the IEA Wind TCP website. The Executive Summary of the 2016 Annual Report was printed as a separate document (1,000 copies) and shipped to members with the Annual Reports.

This, the 39th IEA Wind TCP annual report, lists accomplishments by the close of 2016. The IEA Wind TCP 2016 Overview (Chapter 1) compiles information from all countries and tasks to highlight important statistics and trends. Chapter 2 provides a brief summary of the activities and accomplishments for the 15 active tasks of the TCP. Chapters 3 through 18 provide additional information on each task. Member country chapters (Chapters 19 through 41) describe activities in the research, development, and deployment of wind energy in each participating country during the year that just ended. The *IEA Wind 2016 Annual Report* is published by PWT Communications, LLC in Boulder, Colorado, United States, on behalf of the IEA Wind Executive Committee (ExCo).

Notes

[1] The International Energy Agency (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 in the IEA. For more information, visit www.iea.org.

[2] The IEA Wind implementing agreement, also known as the Wind Energy Technology Collaboration Programme (TCP), functions within a framework created by the 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.

Appendix B

IEA Wind TCP Executive Committee 2016

These are the members who served in 2016. Serving members change occasionally. For the current membership and contact information, visit www.ieawind.org and select IEA Wind TCP Members.

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Appendix C

Currency Conversion Rates for IEA Wind 2016 Annual Report

Country	Currency	1 EUR	1 USD
Austria	EUR	1	1.053
Belgium	EUR	1	1.053
Canada	CAD	0.707	0.744
China	CNY	0.137	0.144
Denmark	DKK	0.134	0.142
Finland	EUR	1	1.053
France	EUR	1	1.053
Germany	EUR	1	1.053
Greece	EUR	1	1.053
Ireland	EUR	1	1.053
Italy	EUR	1	1.053
Japan	JPY	0.0081	0.0086
Korea	KRW	0.00079	0.00083
México	MXP	0.046	0.048
Netherlands	EUR	1	1.053
Norway	NOK	0.11	0.116
Portugal	EUR	1	1.053
Spain	EUR	1	1.053
Sweden	SEK	0.104	0.11
Switzerland	CHF	0.932	0.981
United Kingdom	GBP	1.172	1.233
United States	USD	0.919	1
Source: Federal Reserve Bank of New York (www.x-rates.com) 31 December 2016			

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_2e: 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

Appendix D

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: As part of IEA Wind TCP Task 32 Wind Lidar Systems for Wind Energy Deployment, wind turbine power and loads performance measured with two nacelle-mounted lidars at Nørrekær Enge in Denmark (Photo credit: Anders Ramsing Vestergaard, DTU Wind Energy UniTTe project, www.UniTTe.dk)

Inside front cover photo: Sunrise in Belgium

Back cover photo: Vitor Andrade

IEA WIND TCP

The International Energy Agency Wind Technology Collaboration Programme (IEA Wind TCP) is an international co-operation that shares information and research activities to advance wind energy deployment in member countries. Member countries and organizations form a global network of researchers and policy experts focused on sharing the latest technology research and best practices to overcome specific barriers for wind energy deployment.

Participants include 21 member countries from Europe, North America, and Asia, as well as the Chinese Wind Energy Association, the European Commission, and WindEurope. The IEA Wind TCP is always looking for new members across the globe, and potential new member countries are encouraged to attend meetings and begin the process of joining.

Currently, about 84% of the world's wind power capacity (and nearly all of the world's offshore capacity) resides in the IEA Wind TCP member countries. By the end of 2016, participating countries had installed 44 GW of new wind power capacity across the globe—enough to meet 5.2% of the total electricity demand in those countries. The cost of wind energy has steadily decreased over the years and wind power is becoming the least expensive option for new electricity generating capacity.

Researchers and policy experts lead and participate in 15 research Tasks, addressing specific issues related to wind energy development. These Tasks explore a variety of topics, including offshore wind deployment, component design and testing, the environmental impacts and cost of wind energy, social acceptance of wind energy, and systems engineering and aerodynamic modeling.

This Overview of the *IEA Wind TCP 2016 Annual Report* highlights the work of the 15 research Tasks and provides an extensive summary of the how member countries benefit from wind energy, how much wind power generation each country has deployed, and how policies and research programs will increase wind power's contribution to the world energy supply. The full report is available at www.ieawind.org

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