iea wind

IEA Wind Technology Collaboration Programme

2017 Annual Report

A MESSAGE FROM THE CHAIR

Wind energy continued its strong forward momentum during the past term, with many countries setting records in cost reduction, deployment, and grid integration.

In 2017, new records were set for hourly, daily, and annual wind–generated electricity, as well as share of energy from wind. For example, Portugal covered 110% of national consumption with wind-generated electricity during three hours while China's wind energy production increased 26% to 305.7 TWh. In Denmark, wind achieved a 43% share of the energy mix—the largest share of any IEA Wind TCP member countries.

From 2010-2017, land-based wind energy auction prices dropped an average of 25%, and levelized cost of energy (LCOE) fell by 21%. In fact, the average, globally-weighted LCOE for land-based wind was 60 USD/MWh in 2017, second only to hydropower among renewable generation sources. As a result, new countries are adopting wind energy.

Offshore wind energy costs have also significantly decreased during the last few years. In Germany and the Netherlands, offshore bids were awarded at a zero premium, while a Contract for Differences auction round in the United Kingdom included two offshore wind farms with record strike prices as low as 76 USD/MWh. On top of the previous achievements, repowering and life extension of wind farms are creating new opportunities in mature markets.

However, other challenges still need to be addressed. Wind energy continues to suffer from long permitting procedures, which may hinder deployment in many countries. The rate of wind energy deployment is also uncertain after 2020 due to lack of policies; for example, only eight out of the 28 EU member states have wind power policies in place beyond 2020.

The low cost of energy achieved so far is opening new markets. However, in order to exploit the potential of other aspects of wind energy—like additional services to the grid—markets need to be designed to account for wind energy, and for renewables in general.

Overall, contributions from the IEA Wind Technology Collaboration Programme (TCP) Research Tasks are paving the way for further deployment, cheaper cost of energy, lower risk investments, and removing some of the technological and non-technological barriers to wind energy.

International collaboration is at the core of our activities at the IEA Wind TCP. In 2017 we launched a new community platform aimed at increasing the impact of our activities by better disseminating our work and by creating a global community of experts in wind energy.

I invite you to be part of IEA Wind community and to contribute to the development of wind energy. You can start here: community.ieawind.org

Ignacio Marti
Chair of the Executive Committee, 2016-2018

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IEA WIND TCP 2017 OVERVIEW

WIND ENERGY RESEARCH, DEVELOPMENT, & DEPLOYMENT SUCCESS

Wind energy saw much success in 2017, continuing the trend of upward growth worldwide. Current wind energy cost reduction trends continue, underpinned by an increasingly mature ecosystem of supply chain, developers and operators. Efficiencies of large market volume, gradual technology innovations, and reduction of risk premium also contribute to cost reduction.

Globally, 53 GW of wind power capacity was added during the year, reaching a total of 539 GW (Table 1). Installed capacity grew 11% worldwide, with over 50 GW installed for the fourth consecutive year [1]. A record 4.3 GW of new offshore capacity was installed worldwide, increasing the cumulative capacity by 31% to 18.8 GW [1]. Wind power continues to be the largest non-hydropower source of renewable energy by installed capacity, with a share of 50% excluding hydropower [2].

Table 1. Wind Energy Key Statistics 2017

	IEA Wind TCP Member Countries	Global Statistics [1,2]
Total net installed power capacity (land-based and offshore)	456.6 GW	539.1 GW
Total offshore wind power capacity [2]	18.7 GW	18.8 GW
New wind power capacity installed	42.5 GW	52.5 GW
Electrical annual output from wind	942.5 TWh	1,430 TWh*
Wind-generated electricity as a percent of electric demand	6.1%	5.6%*
* Estimate		

2017 was a landmark year for moving from old subsidy schemes to auctions, which are often market-based and technology-neutral. Land-based wind power auctions were performed in Canada, France, Germany, and Spain. Denmark, Finland, and Ireland are launching technology-neutral auction systems in 2018.

Norway and the United States are planning to move to full market operation for wind plants after their current subsidy schemes end in 2020 and 2021, respectively. China is discussing moving to a wind power tariff, similar to the tariff for coal.

For the first time, in 2017 auctions for offshore capacity were awarded at zero premium over and above the wholesale electricity price (excluding grid connection). This milestone indicates that subsidy-free operation is becoming a reality [3].

The IEA Wind Technology Collaboration Programme (IEA Wind TCP) shares information and engages in research activities (Tasks) to advance wind energy deployment. In 2017, there were 26 contracting parties to this agreement representing 21 member countries as well as the European Commission, the Chinese Wind Energy Association, and WindEurope (Italy and Norway have two contracting parties).

Nearly 85% of the world's wind generating capacity—and nearly all offshore capacity—resides in countries participating in the IEA Wind TCP [1]. These countries added about 43 GW of capacity in 2017, accounting for over 80% of the worldwide market growth [1]. Within the IEA Wind TCP member countries, 457 GW of operational wind power capacity generated 943 TWh in 2017, meeting 6.1% of the total electrical demand.

This Executive Summary of the *IEA Wind TCP 2017 Annual Report* presents highlights and trends from each member country and sponsor member, as well as global statistics.

The annual report also presents the latest research results and plans for the 16 co-operative research activities (Tasks), which address specific issues related to wind energy development. Data reported in previous IEA Wind TCP documents (1995-2016) are included as background for discussions of 2017 events. The annual report is freely downloadable at community.ieawind.org.

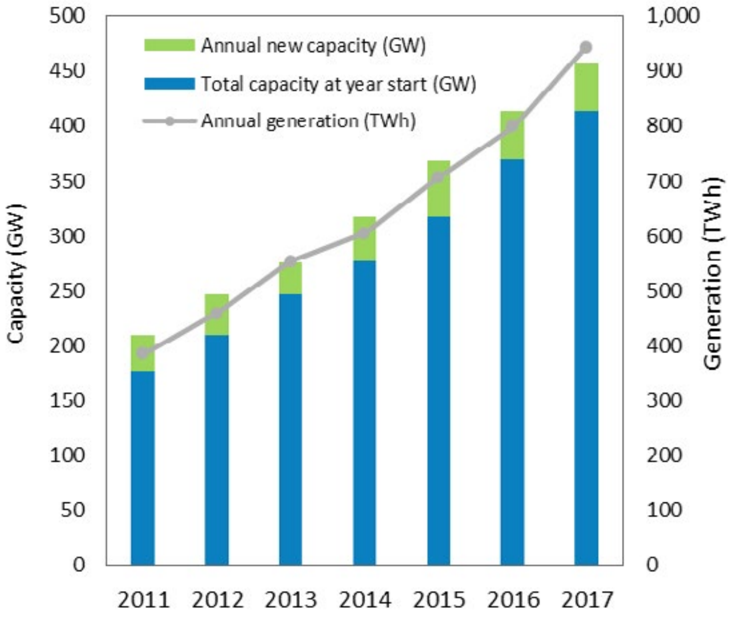

Figure 1. Annual net new and cumulative wind power capacity and electricity production for member countries

PROGRESS TOWARDS POLICY TARGETS

Member countries with 2020 wind deployment targets in place reported a 78% fulfilment of those targets. It is expected that wind will contribute 20% to global electricity supply by 2060 [4].

Wind energy deployment is a key contributor to an energy mix capable of fulfilling the IEA 2 Degrees Scenario (2DS), which calls for transforming the energy system and reducing CO_2 emissions to limit the global temperature increase to 2°C. In 2017, wind produced 6.1% of the electricity supply in member countries on average—up from 5.4% in 2016. The current national targets established by IEA Wind TCP member governments for renewable energy and wind energy are listed at the end of this chapter in Table 11.

Sustained Growth Amid Policy Transitions

Wind power capacity installed in 2017 represented 11% of the global cumulative installed wind power capacity [1]. Although total capacity is increasing, the rate of growth for annual installations declined compared to 2016 (Figure 1).

China, the United States, and Germany continue to lead in cumulative wind capacity. China installed 37% of new world capacity in 2017, followed by the United States (13%) and Germany (12%). The United Kingdom, India, Brazil, and France each installed more than 1 GW [1]. Belgium, Finland, Ireland, Norway, and the United Kingdom increased their cumulative capacity by 20% or more in 2017 [1].

Increasing Momentum for Offshore Wind

Offshore wind annual installations continued to increase in 2017. Globally, 4.3 GW of new capacity was added, up from 2.3 GW the previous year, reaching a total 18.8 GW cumulative capacity (Figure 2).

The United Kingdom, Germany, and China installed 93% of all new offshore capacity in 2017 (1.7 GW, 1.3 GW, and 1.2 GW, respectively). New capacity was also built in Belgium, Finland, Japan, and South Korea. Technology maturity and offshore wind cost reductions are the driving forces behind this momentum.

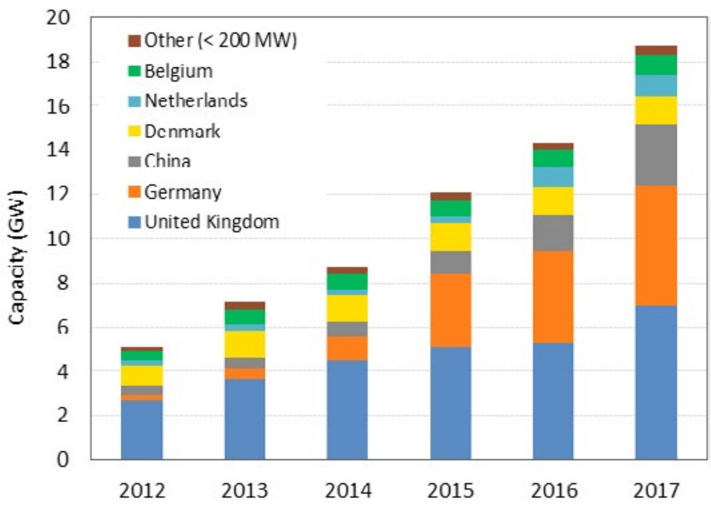

Figure 2. Offshore wind capacity (other: countries under 200MW)

Wind Continues to Grow in the Energy Mix

Wind power continues to steadily increase its share of the energy mix. Since 2009, IEA Wind TCP member countries have increased their wind share in the energy mix at an average rate of 0.44% per year (Figure 3). Wind-generated electricity met almost 5.6% of the world's demand in 2017 [1, 2]. In member countries, wind power met 6.1% of the national demand—an increase from 4.8% on the previous year. Wind-generated electricity within participating countries increased to 942.5 TWh (up 18% from 2016).

Key deployment milestones in 2017 were:

- Eight countries now cover more than 10% of electricity demand with wind; Denmark achieved a record 43% share.
- Annual offshore installations rose to 4.4 GW from 2.3 GW.
- 30 countries now have more than 1 GW of grid-connected capacity [2].

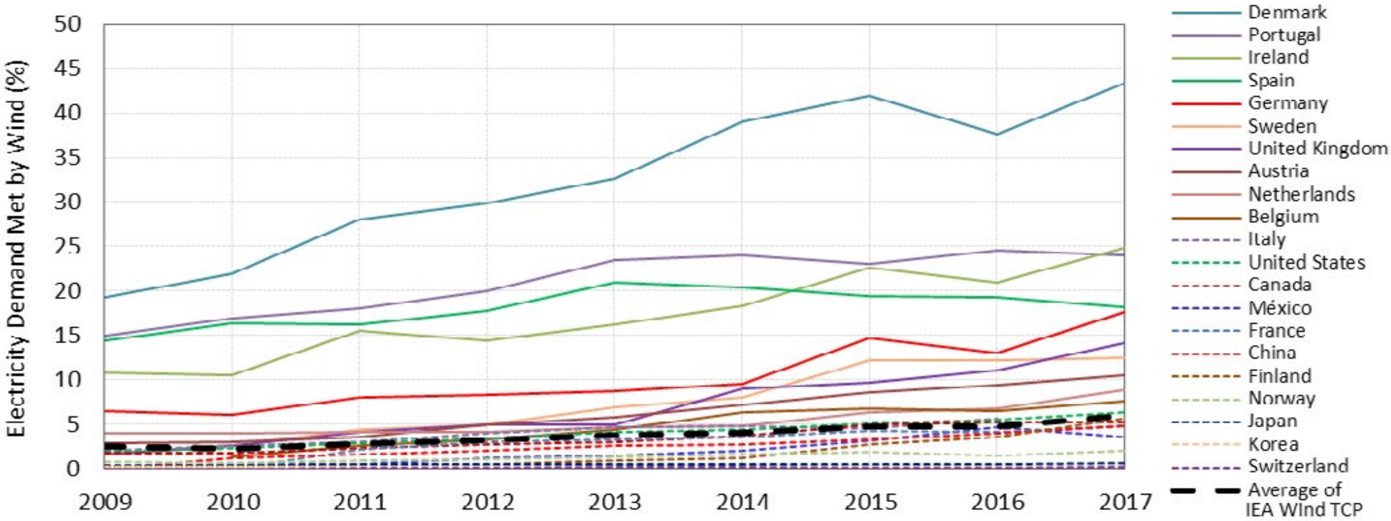

Figure 3. National electricity demand met by wind (note: 2016 was a low wind year in many countries)

Several countries reported new records for hourly, daily, and annual wind production and/or share of wind. In Portugal, wind generated electricity reached 110% of national consumption for three hours and reached a new record for the maximum daily share, with 82% from wind. Spain had a record daily wind production of 330 GWh and instantaneous share of demand of 61%.

China produced 305.7 TWh of wind-generated electricity in 2017—an increase of 26% over the previous year. Germany generated more than 100 TWh and in Denmark a new maximum annual production was reached at 14.8 TWh. The countries with the highest shares of wind-generated electricity consumption were Denmark (43%), Ireland (25%), Portugal (24%), and Spain (18.2%) and Germany (17.7%).

Opportunities for Repowering

In the EU, around 50% of the cumulative wind capacity will reach the end of its operational life by 2030. For example, in Spain more than 3.5 GW of capacity are 15 years or older. As a result, repowering markets are starting to emerge. In 2017, Spain repowered a 21-year-old wind farm by replacing 225 kW turbines with 2.35 MW turbines—achieving a capacity factor increase from 22% to 24% (a 9% improvement).

2020 Policy Targets & Beyond

Governments continue to establish targets for renewable energy sources (RES) and wind energy, design market mechanisms and energy policies, and fund research to reach these targets. Market mechanisms and policies are detailed in Table 4. National R&D budgets for wind research are provided in Table 6. Table 11 lists national targets for member countries.

Most member countries are converging towards their wind deployment 2020 targets as expected—reporting a 78% fulfillment of those targets on average (Figure 4). Italy. Korea, Switzerland announced new target policies in 2017. Sweden targets 100% RES electricity production by 2040 and a new energy agreement is under negotiation in Denmark.

The EU's RES target is being revised, as of June 2018, the EU Parliament had voted to raise the target from 27% to 32%. According to *Renewable Energy Prospects for the European Union,* 327 GW of new wind capacity is required to achieve a 35% RES share in a 2030 scenario [5]. This target requires approximately 16 GW per year annually 2019-2029. However, deployment across Europe is uncertain, with only eight of the 28 EU member states having policies beyond 2020.

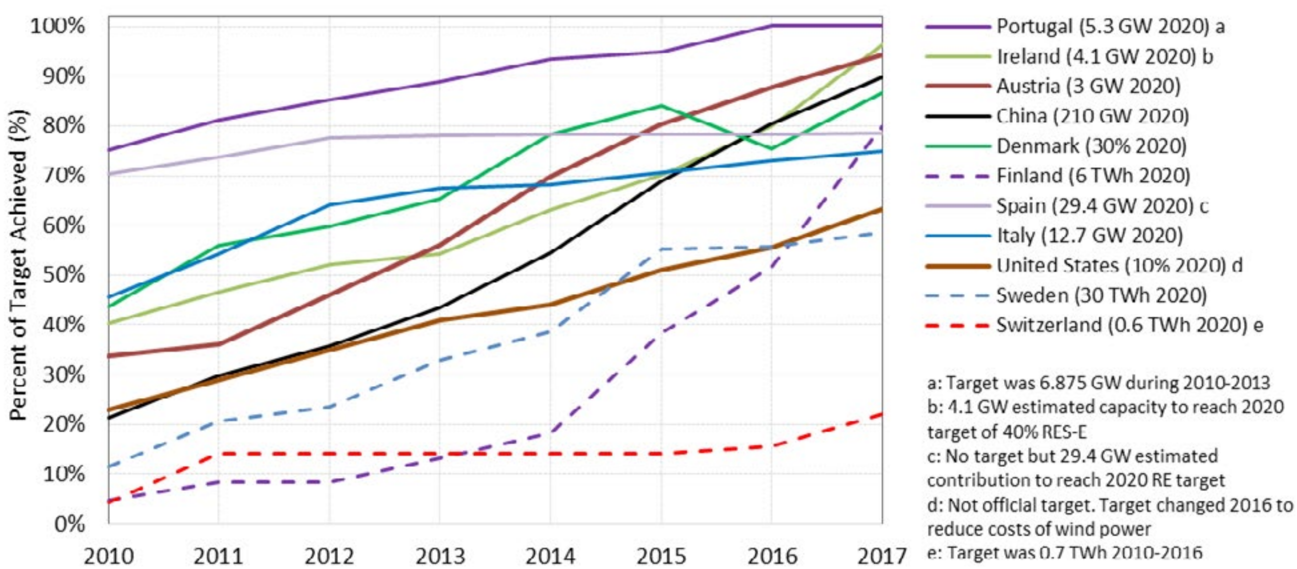

Figure 4. Progress in reaching 2020 wind energy target, % of target reached (target in GW, TWh, or share of electricity)

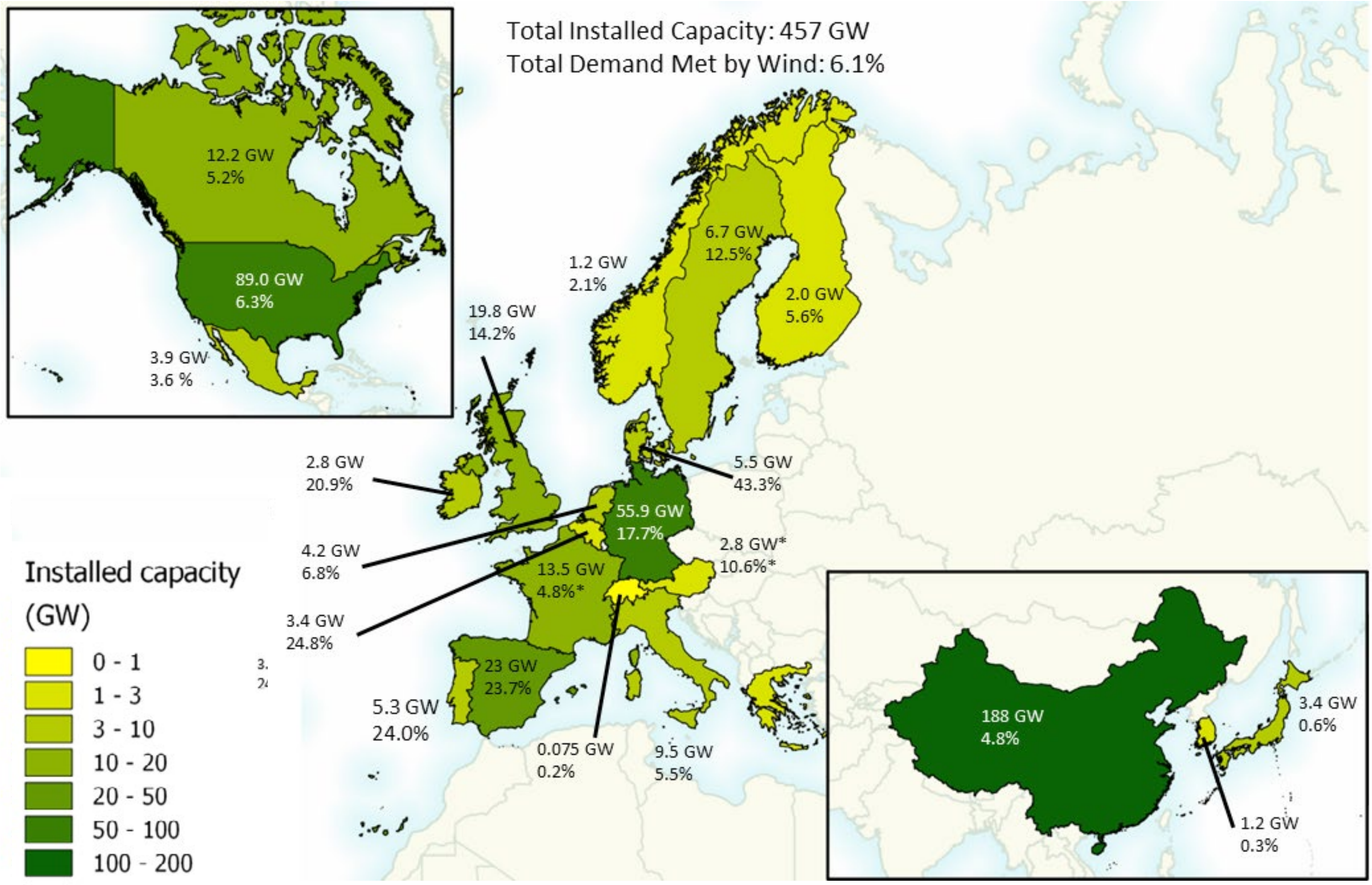

Figure 5. Total installed wind power capacity and wind generated electricity as a percent of national electric demand (*WindEurope 2017)

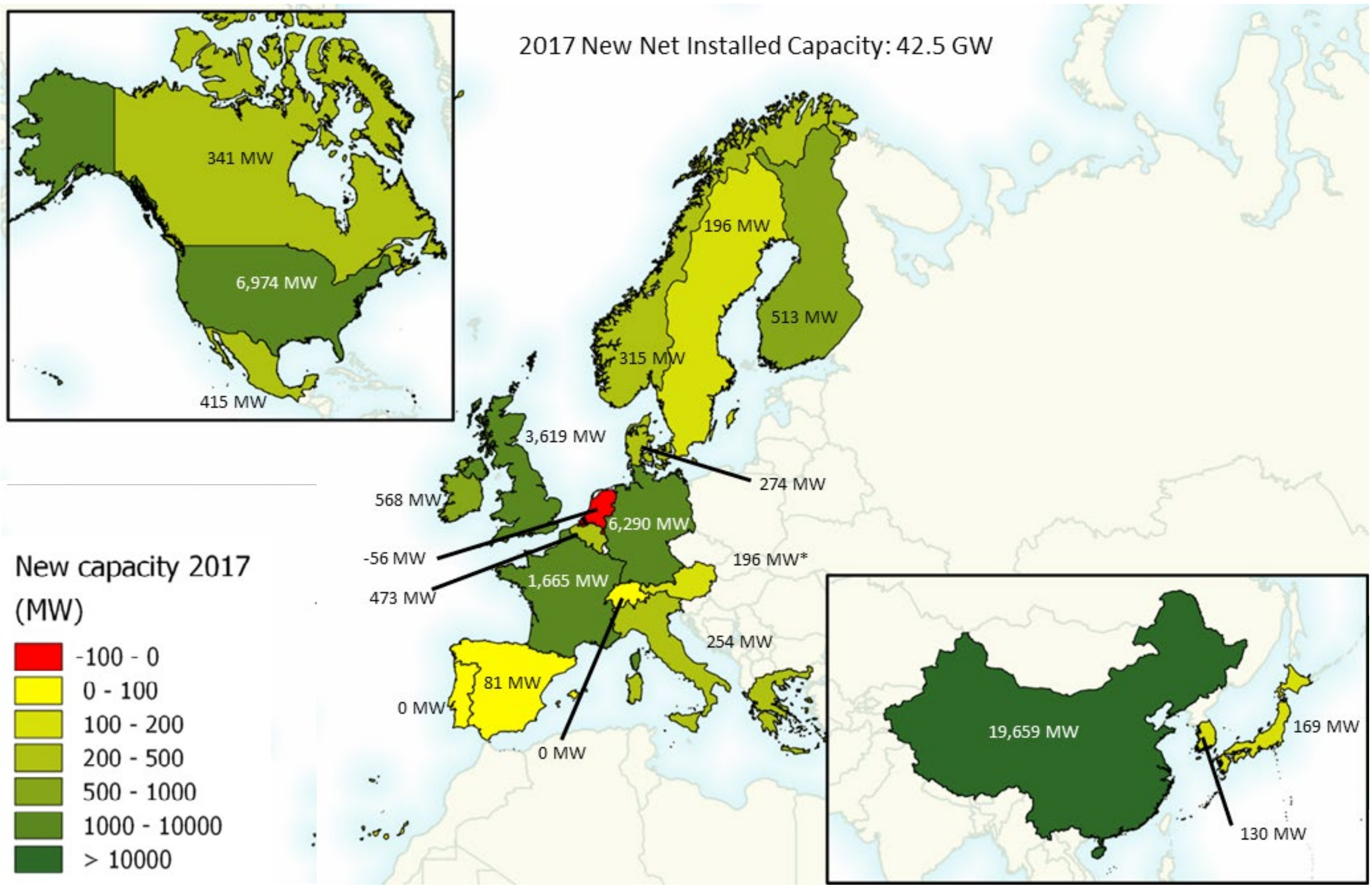

Figure 6. New net capacity installed in 2017 in IEA Wind TCP member countries (*WindEurope 2017)
Note: In the Netherlands, the scaling up of existing wind farms has led to a temporary increase in operational turbines being dismantled

Progress Towards the 2 Degrees Scenario

According to the IEA's *Energy Technology Perspectives 2017* report, more than 20% of global electricity should come from wind by 2060 to achieve climate targets [4]. The IEA's 2 Degrees Scenario (2DS) calls for an ambitious energy system transformation and CO_2 emissions reduction to have at least a 50% chance of limiting the average global temperature increase to 2°C by 2100.

Between 2020 and 2025, offshore capacity needs to triple and land-based needs to increase 1.7-fold to be on track with the two-degree target. To this end, member countries produced 883 TWh of land-based wind-generated electricity in 2017, contributing 86% to the "2 Degrees Scenario" (2DS) global land-based wind target production [4]. The world's land-based wind energy production is on track for 2DS, assuming a similar capacity factor for the IEA Wind TCP members and non-member countries (the latter representing 16% of the world's land-based capacity).

Member countries also generated most of the world's offshore wind production, representing 87% of the 2DS global offshore wind target production for 2017 [4]. The growth in annual installations inspires moderate optimism that countries can close the 2DS target gap in the near future.

Table 2. Top Ten Wind Power Capacity Rankings

	Cumulative Capacity (end of 2017)		Net Capacity Additions (2017)		Increase in Cumulative Capacity (2017)		Capacity Relative to Country Size	
	Country	MW	Country	MW	Country	%	Country	kW/km²
1	China	188,390	China	19,659	Norway	36%	Germany	142
2	United States	88,973	United States	6,974	Finland	34%	Denmark	130
3	Germany	55,876	Germany	6,290	Ireland	27%	Netherlands	101
4	Spain	23,092	United Kingdom	3,619	United Kingdom	22%	Belgium	94
5	United Kingdom	19,836	France	1,665	Belgium	20%	United Kingdom	82
6	France	13,488	Ireland	719	France	14%	Portugal	58
7	Canada	12,239	Finland	513	Germany	13%	Ireland	48
8	Italy	9,496	Belgium	473	Korea	13%	Spain	46
9	Sweden	6,691	México	415	México	12%	Austria	34
10	Denmark	5,503	Canada	341	China	12%	Italy	32

Table 3. Turbine Details 2017

Country	Total Number of Turbines Operating	Average Capacity of All Turbines (MW)	Average Capacity of New Offshore Turbines (MW)	Average Capacity of New Land-based Turbines (MW)	Average Capacity of All New Turbines (MW)
Austria	1,260	2.24	---	---	---
Canada	6,415	1.91	---	2.69	2.69
China	114,244	1.65	3.65	2.06	2.11
Denmark*	4,686	1.17	7.00	3.37	3.51
Finland	700	2.92	3.80	3.32	3.37
Germany	29,844	1.87	5.64	2.98	3.36
Ireland	1,909	1.82	---	2.35	2.35
Italy	6,734	1.41	---	1.94	1.94
Japan	2,225	1.53	5.00	2.16	2.20
Korea	540	2.16	3.00	2.86	2.89
México	2,130	1.85	---	3.19	3.19
Norway	468	2.54	---	3.31	3.31
Portugal	2,743	1.94	---	---	---
Spain	20,142	1.15	---	1.41	1.41
Sweden	3,437	1.95	---	3.37	3.37
Switzerland	37	2.03	---	---	---
United States ++	54,000	1.65	---	2.32	2.32

--- No data available * Turbines above 25 kW ++ Utility-scale

Figure 7. An 83.6-m long blade being tested in the China General Certification Center

PERFORMANCE GAINS FROM WIND TECHNOLOGY IMPROVEMENTS

The trend toward larger turbines continued in 2017, with the average capacity of new turbines installed in member countries at 2.7 MW, up from 2.4 MW the previous year. Capacity factors also increased in many countries compared to 2016 and the cost of wind has become even more competitive.

Turbines Continue to Increase in Size

Over the last ten years, the rated capacity of new turbines has increased by an average of 4% annually in member countries (Figure 8). Table 2 shows wind power capacity rankings for net and cumulative capacity, as well as percent increase for 2017. Table 3 provides details for the turbines installed in 2017.

Blade manufacturer LM-GE tested an 88.4-m blade in 2017—the largest ever manufactured. The next size milestone for offshore turbines is the 100-m+ blade, which is designed to fit the 12-MW, 220-m GE Haliade-X turbine and which may become commercially available in 2021. Turbine towers reaching these new heights are able to access better wind resources. This represents an opportunity to expand the wind market significantly (for example, 69% of the land in Sweden is forested). GE and Max Bögl achieved a record hub height of 178 m in Germany, where they also built a wind power plant integrating a water reservoir (or water battery) and a GE 3.4-MW wind turbine.

The MHI-Vestas 9.5-MW turbine was launched in the market after testing at Østerild, Denmark. The increased capacity of the V164 set a milestone in drivetrain capacity, even though the test turbine had to be taken down after a fire.

Floating offshore wind continues advancing towards commercial maturity. Japan's Fukushima FORWARD II-Hitachi project features a 5-MW wind turbine built on an advanced spar type-floater, which started operation in March 2017. The first commercial floating offshore wind farm, Hywind, started operations in October off the coast of Scotland.

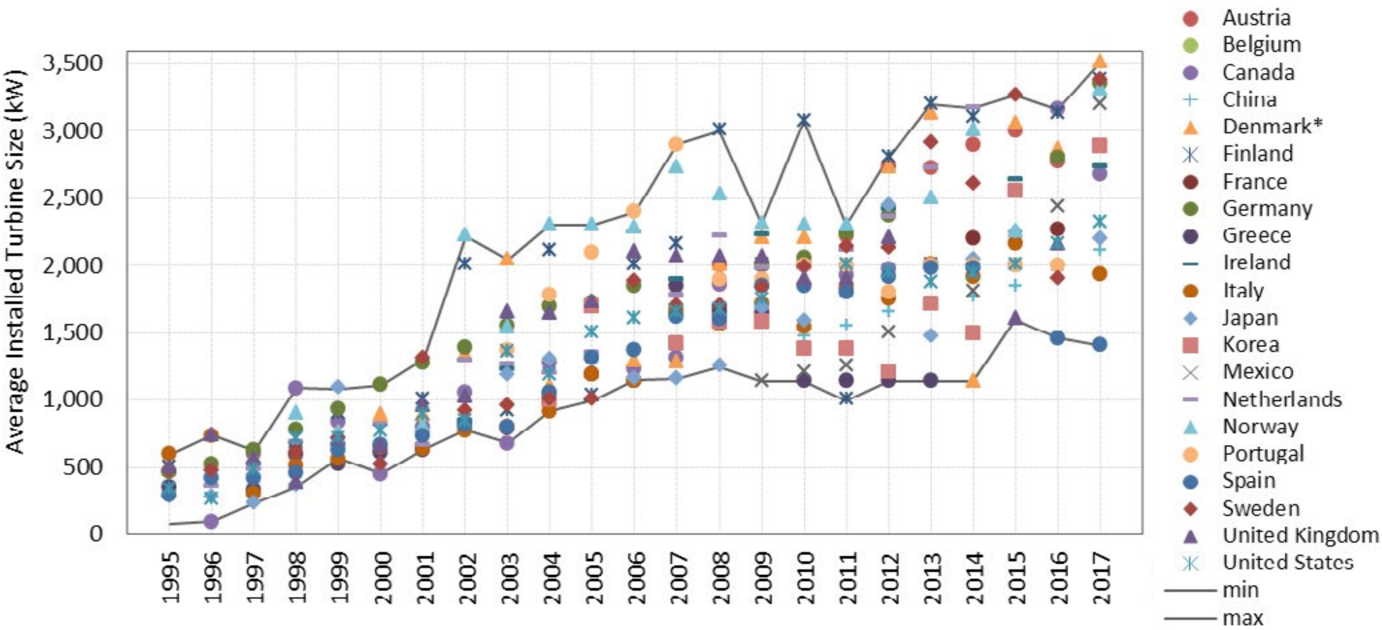

Figure 8. Average size of newly installed wind turbines (note: Denmark includes turbines over 25 kW)

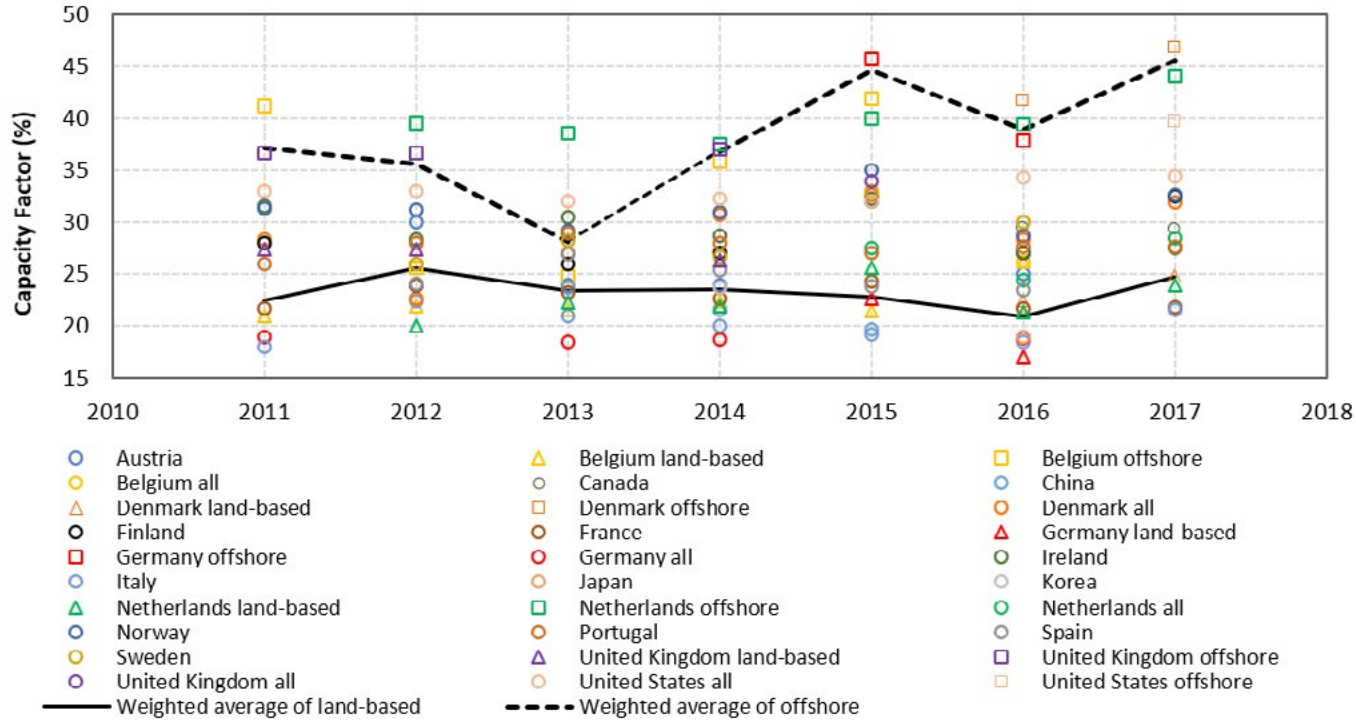

Figure 9. Capacity factors reported (average wind power output); offshore numbers in squares and land based numbers as triangles, combined in dots

Capacity Factors Continue to Increase

In 2017, capacity factors (average wind power output) increased in most countries compared to the previous year (Figure 9). Similarly, the wind index also increased in all reporting countries (Figure 10). The wind index is a measure the quality ofthe wind energy resource relative to the long-term average for a given location or region.

Between 2011 and 2017, land-based wind capacity factors, averaged across member countries, fluctuated between 22.5% and 25.5%. Offshore capacity factors also fluctuated, increasing from 37.1% to 45.6% with a yearly average improvement of 3.5% (this trend is more evident in the offshore case).

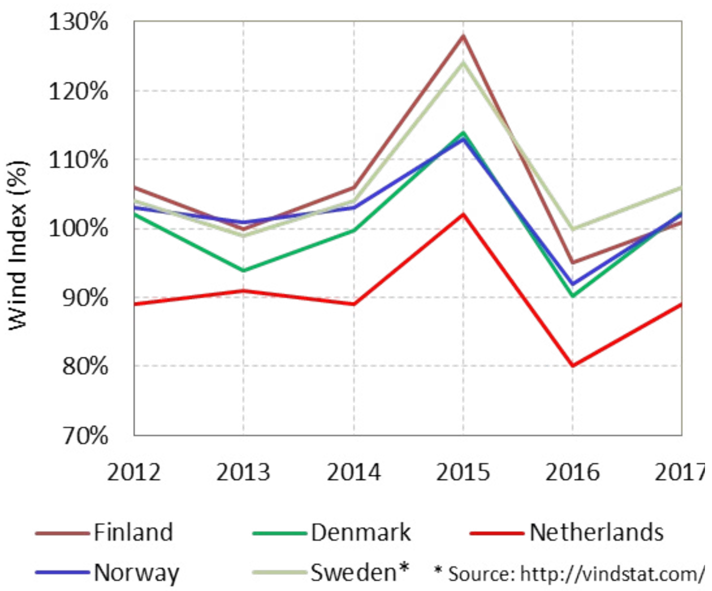

Figure 10. Wind resources reported as wind (production) index, or a measure of how much the wind had blown more or less than expected over a given period

Technology advancement drives the long-term improvement trend, but fluctuations result from annual wind resource variation, fleet age, curtailments, and wind climate in new sites.

Progress Towards Cost Reduction Targets

The wind industry continues to become more competitive. From 2010-2017, land-based wind auction prices dropped 25% on average (4% annually), and the levelized cost of energy (LCOE) fell by 21% (3% annually) [6].

Decreasing auction prices have been reported across IEA Wind TCP member countries. México and Canada reached record low prices in 2017. México reported a price of 14.2 EUR/MWh (17 USD/MWh) and Canada reported a price of 23 EUR/MWh (28 USD/MWh). In Spain, bids were as low as 33 EUR/MWh (40 USD/MWh), the minimum allowed under the Spanish system.

The average LCOE for land-based wind, globally weighted, was 53 EUR/MWh (64 USD/MWh) in 2017—second only to hydropower among renewable generation sources [6]. In Germany, the record-low bid was 22 EUR/MWh (26 USD/MWh) and the lowest average of three auction rounds in 2017 was 38 EUR/MWh (46 USD/MWh). In France, the average land-based auction winning price of 65 EUR/MWh (78 USD/MWh) represents a 21% price drop compared to previously-awarded feed-in tariffs.

In Germany and the Netherlands, offshore bids were awarded at zero premium (over and above the wholesale electricity price, excluding grid connection). In the United Kingdom, a Contract for Differences auction round had two offshore wind farms with record strike prices as low as 58 GBP/MWh (65 EUR/MWh, 78 USD/MWh), meaning that offshore wind prices fell 50% compared to two years before. In Belgium, three planned offshore wind farms will be built at an LCOE of 86 EUR/MWh (103 USD/MWh).

Task 26 Data Viewer: Analyzing the Cost of Wind Energy Trends

In 2017, IEA Wind TCP Task 26 on Cost of Wind Energy developed an online tool to visualize and download data related to wind project statistics for countries participating in the Task (Denmark, EU28, Germany, Ireland, Norway, Sweden, and the United States).

Because of the customizable and user-friendly nature of the platform, users can access several different statistics, including average, median, minimum and maximum levels, weighted average and box-and-whiskers. Users can also filter countries and years, zoom to a specific date range, as well as download the figures or the underlying data in csv format for further data analysis.

The information available through the Data Viewer provides the basis to analyze trends in technology and cost, while allowing cross-country comparison in a convenient way. These project-level figures can help researchers understand and highlight the differences in technology trends of land-based wind over time and in different countries.

You can view the Data Viewer by visiting the Task 26 website: community.ieawind.org/task26/dataviewer.

Figure A. Wind capacity and targets for Denmark, 2000-2020

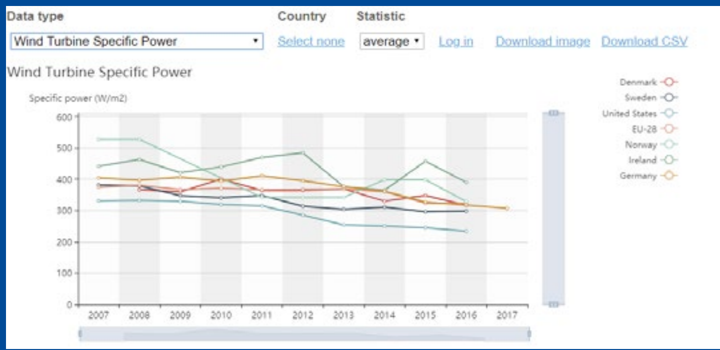

Figure B. Wind turbine specific power, 2007-2017

The average cost of land-based projects in member countries was 1,448 EUR/kW (1,737 USD/kW) in 2017 (Figure 11). Project costs have fallen 32% since their peak in 2011.

IEA Wind TCP Task 26 focuses on analyzing the cost of wind energy and developed a web-based data viewer for researchers to visualize and download data related to wind project statistics (see above highlight).

The Data Viewer includes wind power data such as installed capacity, turbine characteristics (nameplate capacity, rotor diameter, specific power, hub height, IEC wind class), full load hours, and project size, along with cost data such as investment cost, operations and maintenance (O&M) cost, and weighted average cost of capital (WACC).

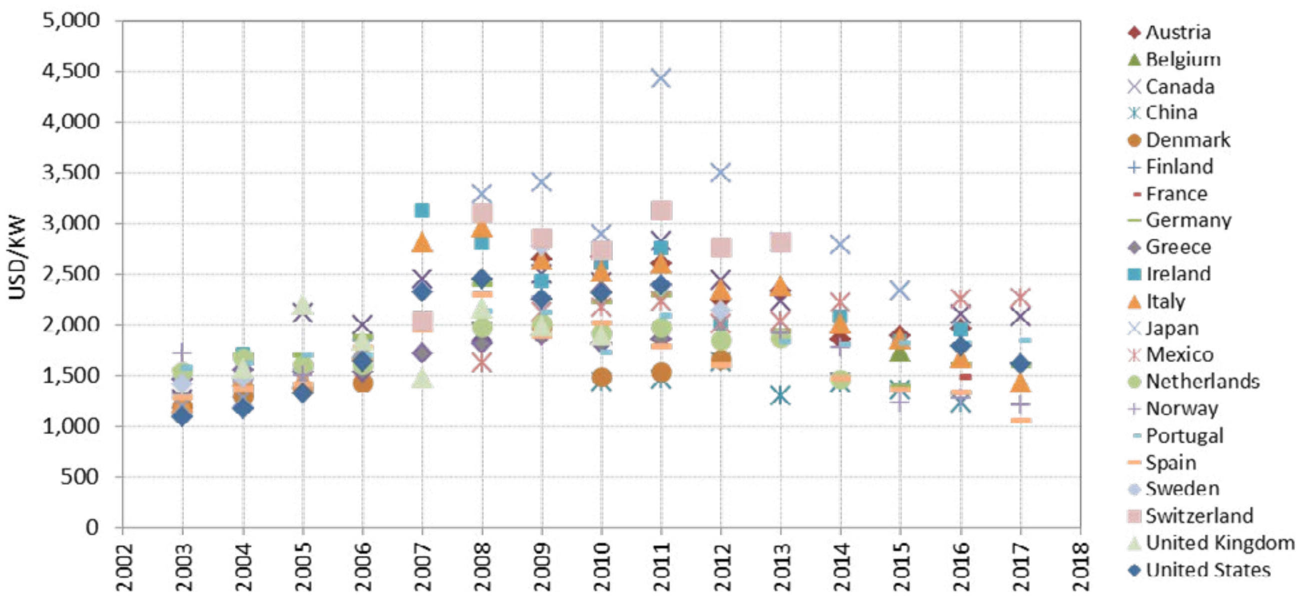

Figure 11. Land-based wind power project cost history from reporting IEA Wind TCP countries

MITIGATING DEPLOYMENT CONSTRAINTS

Member countries work together to tackle deployment constraints because many countries experience similar growth impediments. In many cases, policy actions can help, or even remove, these barriers.

Becoming Competitive in Electricity Markets

Considerable reductions in levelized cost of energy (LCOE) have made wind one of the cheapest options for power generation. Low electricity market prices were reported as a beneficial outcome of wind deployment in Portugal, Germany, and Denmark. However, in Norway and Sweden both electricity market and green certificate prices have been low, resulting in very low income for wind producers. Lower prices have created increased demands on financial support mechanisms (as in Finland). Incentivizing wind power investment has been a major instrument used to improve deployment.

Table 4 provides an overview of the subsidy systems and other tools employed by member countries to increase wind power deployment.

Corporate sourcing is also an emerging market driver for wind energy. Power purchase agreements (PPAs) with non-utility organizations are enlarging the market in many European countries, especially for projects outside subsidy systems. In the United States, PPAs and qualifying facility contracts signed in 2017 accounted for 5,496 MW (63% utilities, 37% corporations/other).

Table 4. Market Mechanisms and Policies, 2017

	Incentive Programs	Description	Countries Implementing
Financial Incentives	Auctions for guaranteed price	Competitive bidding procurement processes for a guaranteed electricity price from wind energy or where wind energy technologies are eligible	Canada, Denmark, Germany, Italy, United Kingdom
	Auctions for premium	Competitive bidding procurement processes for a premium in addition to the electricity market price for wind-generated electricity or where wind energy technologies are eligible	France
	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	Canada, China, Denmark, Germany, Ireland, Italy, Japan, Korea, Portugal**, Switzerland, United Kingdom
	Variable premium over market price	A variable premium paid is the difference between a guaranteed price and the electricity market price (including contract of difference)—producers are in the electricity markets	Denmark, Finland, Germany, Netherlands, United Kingdom
	Fixed premium over the market price	A fixed premium is paid over the electricity market price—producers are in the electricity markets	France
Market-oriented Regulatory Incentives	Renewable portfolio standards, production obligation, renewables obligation	Mandate that the electricity utility (often the electricity retailer) source a portion of its electricity supplies from renewable sources	Canada, Italy, Korea, Norway, United Kingdom, United States*
	Green certificates	Approved power plants receive certificates for the amount (MWh) of electricity generated from renewable sources. Electricity and certificates are sold; certificate prices are determined in a separate market in which consumers are obligated to buy a minimum percentage of their electricity from renewable sources	China, Denmark, Italy, Netherlands, Norway, Sweden, United States*
	Electric utility activities	Activities include: green power schemes; allowing customers to purchase green electricity; wind farms; various wind generation ownership and financing options with select customers; and power purchase models for electricity from wind projects	China, Denmark, Ireland, Netherlands, Norway, Sweden, United States
	Carbon tax	A tax on carbon that encourages a move to renewables and provides investment dollars for renewable projects	Canada* (BC, AB, QC, ON), Ireland, Netherlands, 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	Netherlands, United Kingdom
	Spatial planning activities	Areas of national interest that are officially considered for wind energy development	China, Denmark, Finland, Ireland, Korea, Netherlands, United Kingdom
	Special incentives for small wind	Reduced connection costs; conditional planning consent exemptions; value-added tax rebate for small farmers; accelerated capital allowances for corporations; can include microFIT	Canada, Denmark, Ireland, Italy, Korea, Netherlands, Portugal, United Kingdom, United States

* Program(s) administered at regional or state-level; ** Only available for pending projects, including WindFloat Atlantic Offshore Project

Figure 12. Wind farm in Jiangsu province, China (Photo credit: CWEA)

One important step towards the full electricity market operation of wind power plants is participating in the system services markets. Wind farm operators can get additional income by entering shorter term system services markets for frequency and voltage support services. Continuous trading environments will require wind farm operators to interact more with the market. In Ireland and Spain, many wind power plants have performed compliance tests to ensure plants are compliant with the rules of providing system services. Similar tests are beginning to be performed in Alberta, Quebec, and Nova Scotia, Canada, with system operators observing field tests for inertia emulation and ability to respond to automatic generation control (AGC) signals. In Spain, a significant number of services were procured in 2017 for frequency control and load following.

Reducing Wind Power Curtailment

According to the IEA Wind TCP Task 25 on grid integration, curtailment or refusal to transmit wind-generated electricity is a signal of integration challenges. Curtailment has presented the greatest challenge in China, with a loss of 12% of the wind-generated electricity in 2017 and 15% in 2016. Originally, slow deployment of transmission capacity and inability to connect to the grid contributed to this problem. In 2017, China's curtailment was increasingly due to operational practices caused by the inflexibility of coal power-generation, particularly when combining both electricity and heat in the same coal-fired plant. In China, mitigation methods that are being encouraged include a new certificate system, inter-provincial compensation, increasing peak regulation capacity, and high-voltage transmission lines.

In Germany, delays in the transmission system build-out from the north to the south are causing high redispatch costs for the system operator and increasing wind power curtailment. However, even under these conditions curtailment is still below 4%. System operators in Denmark, Ireland, Portugal, and Spain achieved high instantaneous shares of wind without technical problems in 2017. For example, in Ireland, where wind contributed to 25% of electricity demand, curtailment was less than 4%.

New Transmission Improving Integration

According to Task 25's research, building more transmission capacity is one of the most effective enablers of wind integration. The rate of build out and reinforcing land-based grids to host increasing wind energy capacity while minimizing curtailment are crucial for wind energy deployment.

Several nations have made efforts to increase transmission capacity or increase wind energy on the grid. Japan announced a grid-enhancement plan in the north that will deploy 2.8 GW of transmission capacity, tapping into wind resources in a sparsely-populated region. Wind farm operators will share the construction costs for the project.

In the United States, a program for dynamic line rating of transmission power lines continues, allowing for better use of existing power lines during windy periods. In France, the system operator RTE was made responsible for building the grid for offshore wind power plants, in a system similar to those used in Denmark, Germany, and the Netherlands. In Sweden, a developer subsidy to offset grid costs was considered.

Seeking Ways to Improve Public Acceptance

Task 28 focuses on social acceptance of wind energy. Several studies indicate that wind is one of the most preferred energy sources. Despite this fact, social acceptance and environmental impacts continue to be challenging for development projects. Improving acceptance has become a high priority in countries such as Ireland and Switzerland.

Several factors relevant to wind project acceptance include high-density populations (Italy, Korea, Netherlands), tourism and landscape impacts (Italy), and noise (Finland). In Finland, public concern about noise and infrasound forced the subsidy system to end prematurely. In response, the government commissioned a study on the health effects of wind power. The findings informed the development of a new auction-based renewables support scheme and has helped calm heated discussions on the topic [7].

In the United States and Switzerland, research projects have been used to determine the flight paths of birds and bats in order to understand and measure the impact of wind installations on these species. Task 34 works to resolve the environmental effects of wind energy by promoting better understanding of environmental issues and publicizing solutions for wildlife challenges.

Other methods of improving social acceptance reported by member countries include using early stakeholder engagement (Austria, Belgium) and incentivizing local communities, including ownership stakes (Canada, France, Ireland).

Legal/Regulatory Matters Hinder Deployment

Wind energy still suffers from lengthy permitting procedures, as reported by Belgium, France, Italy, Japan, México, and the Netherlands. This is due to factors such as the interaction of wind projects with civilian and military aviation, environmental constraints, and administration at the national and regional levels, including a lack of specialized professionals.

In some countries, setback distances, noise limits, or interference regulations with civil aviation and military radars are tightening (France, Poland, Sweden, the United Kingdom, and Baltic countries).

On the positive side, in 2017 there were several improvements by authorities to tackle these issues:

- In France and Belgium, one-stop shops were launched to simplify permitting procedures.
- Regional authorities were given a more defined role in solving permitting hurdles in Belgium and Switzerland. Switzerland also declared renewables a national interest.
- In Japan, wind power projects were allowed to apply for FIT during the Environmental Impact Assessment (EIA) process.
- Sweden reported challenges with icing and forested landscapes and will be addressing them through its national research program.

In the United States Department of Energy's WINDExchange engagement effort is helping to address siting and development concerns by providing information to stakeholders. The United States is also continuing work on the Wind Turbine Radar Interference Mitigation Working Group, a collaboration among several governmental bodies. Further, the United States Bureau of Ocean Energy Management is adopting the "design envelope" approach used in some European countries, to allow for flexibility in the timing of offshore wind project design decisions.

Transition Towards New Tender Mechanisms

For many countries, 2017 was a year of transition to new support schemes and tender mechanisms. The regulatory framework is improving market compatibility in Europe. In some cases, the transition to a new incentive system results in a gap between incentives. If such a gap occurs in the final years leading up to a national target deadline (i.e., 2020 targets), their ability to achieve the target might be compromised. Additionally, a lack of insight into future incentive systems creates uncertainty in countries like Germany, Ireland, and Finland.

Long-term visibility and stable regulatory frameworks remain crucial for wind energy deployment after 2020. Several of the post-2020 wind power targets that have been announced are very ambitious (Denmark, Italy, Korea, and Sweden). However, only eight out of the 28 European Union Member States have renewable energy plans beyond 2020. In Japan, wind is still seen as a limited resource, largely due to unsolved power system integration issues.

An increasing proportion of installed capacity will reach its end of life between 2020 and 2030, therefore a regulatory framework for repowering is needed. By 2030, 50% of the current cumulative installed capacity in Europe will have reached the end of its operational life. In the United States, the average age of the wind fleet will be 14 years in 2030 according to IHS Markit.

Figure 13. Final installation phase of a 100-m concrete wind turbine tower at the Instituto Nacional de Electricidad y Energías Limpias' (INEEL) Regional Centre of Wind Technology (CERTE) in Juchitan, Oaxaca, México (Source: Cezanne Murphy-Levesque)

SOCIETAL BENEFITS OF WIND ENERGY DEPLOYMENT

Wind energy benefits society by contributing solutions to the energy trilemma: sustainability, affordability and security of supply. Wind can revitalize economies with new industries and employment. It also provides electricity to communities with limited access to electricity, as in México.

Industry Revenues & Jobs

Wind energy improves national economic indicators such as trade balances; for example, Ireland reported that wind energy displaced an estimated 200 million EUR (240 million USD) of fossil fuel imports in 2017.

Wind power also increases both capital stock and domestic and foreign direct investment in productive infrastructure. Additionally, installation construction activity results in increased government taxation revenue. Employment is generated throughout the wind plant's lifetime, most intensively during design and construction, but also during O&M and decommissioning stages. The United States reports that more than 80% of 2017 wind development was in low income counties. Land lease payments are a significant benefit in the United States, and real estate tax revenues are important in Finland.

Table 5. Capacity in Relation to Estimated Jobs and Economic Impact, 2017

Country	Capacity (MW)	Estimated Number of Jobs	Economic Impact (million USD[a])
China	188,390	507,000*	---
United States	88,973	105,500⁺	11,000⁺
Germany	55,876	160,200*	15,245
Spain	23,092	22,468	2,710*
United Kingdom	19,836	2,000	---
France	13,488	19,000	---
Canada	12,239	---	1,116*
Italy	9,496	26,000	3,927
Sweden	6,691	---	---
Portugal	5,313	3,250	1,348*
Denmark	5,503	> 30,000*	---
México	3,942	1,300*	---
Ireland	3,368	3,400*	---
Austria	2,828	1,490*	408*
Korea	1,165	2,424*	943*
Switzerland	75	---	39*
Total		>870,000	>45,000

[a] Applicable conversion rate EUR to USD: 1.128
* Values from 2016
⁺ Source: American Wind Energy Association

Wind manufacturing jobs are even relevant in countries that do not have turbine manufacturers like Belgium, France, Norway, and United Kingdom, as well as those without a national offshore market like Spain. In the United Kingdom, the nationally-sourced content of offshore wind power plants has increased to 48%.

The wind industry expanded in 2017 and member countries reflected this growth. Table 5 shows the estimated 2017 labor and economic turnover effects of wind energy by reporting member countries. The United States' wind industry had a turnover, or gross revenues, of approximately 11 billion USD (9.2 billion EUR).

Total wind power investments in Europe decreased from 2016 despite increased installations, largely due to lower offshore investments and capital expenditure reductions in offshore and land-based projects. However, European turbine manufacturers continued exporting; the EU trade balance was a 2.4 billion EUR (2.7 billion USD) positive in products and services, with 7.8 billion EUR (9.4 billion USD) in exports and 5.4 billion EUR (6.7 billion USD) in imports.

As wind technology matures, industry consolidations continue. In the United States, four manufacturers control 99% of the market, and in China the top five manufacturers control a 67% share (up from 54% the previous year). The Siemens-Gamesa merger was also completed in 2017. Meanwhile, manufacturers focusing on small to mid-sized turbines are emerging in Belgium (Xant) and the Netherlands (EWT) to cater for markets no longer served by large manufacturers (which are phasing out machines below 2 MW).

Employment in the wind sector increased in 2017 in China, North America, and Europe. Reporting member countries estimated that there were more than 870,000 full-time equivalent jobs related to wind energy in 2017 (Table 5).

Other key developments in employment were:

- China estimates that the number of jobs will grow from 500,000 to about 800,000 by 2020.
- The United States wind industry accounts for more than 100,000 jobs, and "wind turbine technician" is the second-fastest growing job in the country.
- In the EU, the wind industry employs more than 260,000 people, with about 150,000 in Germany, and 20,000–30,000 jobs each in Denmark, France, Italy, and Spain.
- In the Netherlands, an estimated 10,000 new wind energy jobs will be created in the next ten years.

Environmental Benefits & Smaller Footprint

Several member countries calculated the avoided CO_2 emissions (million tons/yr) attributable to wind energy deployment. In many countries, wind is the largest contributor to emission savings from renewable energy (Denmark, Germany, Ireland, Spain, the United Kingdom and the United States). In the United Kingdom, 2017 was the greenest year ever, as wind-generated electricity outproduced coal plants more than 75% of the year.

In addition to CO_2 reductions, setting targets for air quality and reducing other emissions is becoming more prominent in countries like China and Korea. Several countries acknowledge these important benefits, including Austria and China.

China estimated that wind power saved about 109 million tons (Mt) of standard coal and reduced 277 Mt of CO_2, 0.95 Mt of SO_2, and 0.8 Mt of NO_x in 2017. In 2017, the United States' wind generation (254 TWh) displaced about 189 million metric tons of CO_2, reducing its electric sector's emissions by 11%. Wind production also displaced approximately 0.188 Mt of SO_2 and 0.122 million tons of NO_x.

México estimates that developing 12 GW of wind power by 2020 would help reduce emissions by more than 20 Mt of CO_2 by 2020—10% of its national mitigation target. Belgium reported positive environmental impacts from offshore wind, including increasing biodiversity on support structures.

VALUE OF RESEARCH, DEVELOPMENT, AND INNOVATION

National R&D efforts throughout member countries continue to build expertise, facilitate innovation, and drive down the cost of wind energy.

National R&D Funding & Priorities

National budgets for public wind R&D are shown in Table 6. At the country level, wind energy R&D funding declined slightly in 2017. Of the eleven countries reporting R&D budgets in 2017, four increased their funding (Germany, México, the Netherlands, and Switzerland), while seven reported reduced budgets compared to 2016. The EU also reduced its Horizon 2020 (H2020) budget for wind-related projects by 42%. However, public R&D funding varies from year to year due to a number of reasons, and quantifying the budget share allocated to wind energy is difficult because research topics can be cross-cutting.

The European Commission drives wind R&D priorities through the Strategic Energy Technology (SET) Plan, which aims to continue deploying renewables on a large scale. The H2020 program provides funding instruments to reach this goal.

Table 6. National Wind R&D Budgets for Reporting Countries, 2010–2017

Country	Budget (million USD)							
	2010[a]	2011[a]	2012[a]	2013[a]	2014	2015	2016	2017
Canada		7.8	5.8	5.0	4.7*	2.3	3.4	3.3
China	---	---	---	---	---	11.7	1.4	---
Denmark[b]	24.2	1.0	11.5	24.2	---	---	15.4	---
European Commission	47.0	36.7	80.9	90.5	29.9	315.0	68.5	40.0
Finland	5.2	12.9	2.8	4.3	1.2	1.9	1.9	0.0
France	---	---	---	---	---	---	---	---
Germany	71.2	81.2	78.3	36.8	38.5	85.4	86.2	96.0
Ireland	0.4	0.4	1.1	---	---	---	---	---
Italy	4.0	4.0	3.9	4.1	3.6*	2.7		---
Japan	24.6	42.9	55.3	47.5	63.8	127.9	72.2	62.3
Korea	38.1	37.7	44.7	49.1	---	---	30.0	---
México	---	---	---	---	1.4	3.5	2.3	1.5
Netherlands	51.1	9.2	11.6	7.0	4.5	---	---	5.3[c]
Norway	16.7	19.7	22.7	18.2	15.0	10.2	10.8	7.3
Spain	115.9	115.9	158.2	117.8	---	94.0	85.5	13.2
Sweden	14.5	14.5	14.2	14.9	7.8	7.7	7.7	7.3
Switzerland	0.5	0.5	0.5	0.5	0.5	0.6	0.7	0.8
United States	80.0	80.0	93.5	68.2	52.2	107.0	95.45	90.0

--- No data available
* Estimates
[a] Currency expressed in year of budget (not adjusted to present value)
[b] Projects supported by public funds
[c] Excludes funds of the general renewable energy program

Research Initiatives & Results

Member countries highlighted key topics driving ongoing and future R&D activities (Table 7). This table shows national priorities, many of which are largely aligned with the active IEA Wind TCP Tasks, which are summarized in the next chapter. A review of each Task's annual activities follows in the subsequent chapters of this report.

Operations & maintenance: Several Chinese OEMs introduced new wind turbine monitoring and control systems, which can include functions like precise control and supporting O&M through intelligent diagnosis.
In the United States, the Atmosphere to electrons (A2e) initiative conducted wind plant optimization research to understand wind plant operating environments through systems-level research and high-fidelity modeling.

In Europe, the LEANWIND project aimed to provide cost reductions across the offshore wind farm lifecycle and supply chain through the application of lean principles and the development of new technologies and tools.

Grid integration: EirGrid (Ireland) and Smart Wires (United States) successfully tested the SmartValve, a technology that allows grid operators to dynamically adjust the reactance of electricity lines.

Wind measurement: The Technical University of Denmark (DTU) used lidar to measure 3-5 km in front of the wind farm, 5-10 minutes before it hits the turbines. NOWITECH and Fugro developed a floating lidar buoy in Norway.

Wind resource assessment and forecasting: In Japan, the New Energy and Industrial Technology Development Organization (NEDO) developed a 500-m grid resolution offshore wind resource database for areas within 20 km of the Japanese coastline.

Wind farm modeling: NORCOWE and Uni Research in Norway and Aalborg University in Denmark built a comprehensive model of a wind farm with 80 10-MW wind turbines, for developers to optimize a wind farm layout.

Table 7. National R&D Topic Highlights

R&D Topics	Countries	R&D Priorities
Operation & Maintenance	Canada, China, Denmark, Japan, México, Netherlands, Norway, Portugal, Spain, United Kingdom, United States	Condition monitoring of drive train and rotor, drone and remote inspection, virtual reality-assisted maintenance, enhanced O&M data analytics, offshore operational planning tools, component lifetime monitoring, life extension analysis
Integrating wind energy into power systems	Belgium, Canada, Denmark, Finland, Ireland, Netherlands, Spain, Sweden, United States	Smart grid, flow control on grids, new concepts for transmission like high voltage direct current (HVDC)
Floating offshore wind	Denmark, France, Italy, Japan, Korea, Norway, Spain, United Kingdom, United States	Floating installation of foundations and turbines, modeling and demonstration of floating wind power systems
Electrical systems for offshore wind	Denmark, Netherlands, Spain	Offshore substation optimization, HV inter-array cables, deployment of inter-array cables
Other offshore wind	Denmark, Japan, Netherlands, Norway, Portugal, Spain, United States	Substructure design, seabed interaction, wind farm construction, pile driving operation, float and sink foundation concepts, special purpose vessels and service cranes
Wind in cold climates	Austria, Canada, China, Finland, Spain, Sweden, Switzerland	Development of ice prevention systems and anti-ice coatings, operations in cold climate conditions
Turbine upscaling	Denmark, France, Germany, Sweden, United States	Design considerations for larger turbines (20 MW), high towers and large rotors for increased energy capture and forested areas
Manufacturing methods, quality, and reliability	China, Denmark, Germany, México, Spain, United Kingdom, United States	Automation in component manufacturing, 3D printing for repairs and spares, quality evaluation in component manufacturing for blades and drivetrains, reliability assessment
Environmental impact and social acceptance	Canada, Denmark, Ireland, Norway, Switzerland, United States	Wind turbine noise, interaction with avifauna such as birds and bats
Wind resource assessment and forecasting	Germany, Japan, Netherlands, Norway, Switzerland, United States	Forecasting of site-specific wind resources, effect of different variables on wind speed and wind power forecasts at turbine hub heights
Component testing methods	China, Belgium, Denmark, Germany, United States	Blade and drivetrain testing, climatic testing facilities
Materials	Denmark, Netherlands, United Kingdom, United States	New materials for blades and towers: laminate layouts, blade repair solutions, corrosion, coatings, and blade erosion
Energy storage	Belgium, China, Spain, United States	Integration of storage solutions with wind
Small wind turbines	Austria, Ireland, México, United States	Turbine certification, siting, cost competitiveness
Wind farm layout optimization	Denmark, Norway, Switzerland, United States	Cost-effective, time-saving assembly and installation of offshore wind farms, more efficient electricity use for consumers
Wind measurement	Denmark, Norway, Spain, United States	Floating lidar, development of next generation lidar
Wind turbine control	Germany, France, United States	Innovative control solutions, such as feeding from lidar or blade sensors
Innovative concepts	Denmark, France, Germany, Italy	Multi rotor, airborne wind energy

Figure 14. The five "Float-and-sink" gravity based foundations for the Blyth Offshore Demonstration project being manufactured at a dry dock in Newcastle (ORE Catapult, United Kingdom)

Offshore wind: In the United Kingdom, Statoil installed the world's first floating grid-connected offshore wind park. The 30-MW Hywind pilot project achieved a 65% capacity factor from November 2017 through January 2018. In Spain, the ELISA project tested a small-scale self-buoyant precast concrete telescopic tower and a foundation for crane-less offshore wind turbine installation. In Norway, IFE and NOWITECH developed software that performs integrated simulations of structures, including wind and sea loads.

Cold climates: A study of 23 wind farms across Canada from 2010-2016 examined wind farm performance in cold climates. The results demonstrated an average production penalty of 3.9%. Goldwind, in China, developed a new de-icing system comprised of anti-icing coating, a blade heating system, and an icing safety control mode.

Wind turbine upscaling: In 2017, the INNWIND-EU projects were completed. Twenty-eight partners with a near 20 million EUR budget designed ten 20-MW offshore wind turbines and engaged in hardware testing of key components. The AVATAR project, which developed and validated aerodynamic models for future 20-MW wind turbines, also concluded in 2017.

Innovative concepts: Vestas tested a wind turbine with four rotors, in an effort to reduce the cost of energy in specific niche applications. The German company EnerKite GmbH developed a 100-kW, container-based airborne wind energy converter with optional storage solution (EK200) to enter the market by 2020. In France, BladeTips Energy produced downscaled prototypes of an airborne wind energy system.

Environmental impact and social acceptance: In the United States, Sandia National Laboratories and the National Oceanic and Atmospheric Administration (NOAA) partnered to develop a geographic information system that will aid officials in evaluating the potential impacts of wind turbines on radar systems, including weather radars.

Testing methods: LM Wind Power and DTU developed a new method to observe how turbine blade fatigue damage evolves.

Small wind turbines: Integrated Roof Wind Energy System (IRWES) investigated a roof-mounted, venturi-like structure integrating a vertical axis wind turbine.

New Test Facilities & Demonstration Projects Underpin Wind Industry Progress

Several countries conducted tests for grid integration and components, as well as commenced operations in new facilities and demonstration projects or advanced their design and construction (Table 8). These projects reflect the industry's appetite for offshore wind, particularly floating concepts and the novel installation and balance of plant solutions. Table 8 highlights several of the test and demonstration facilities in IEA Wind TCP member countries.

Transnational Collaborative Research Continues to Drive Wind Technology Forward

It is difficult to conceive the progress under way in the wind sector without a continuous collaborative R&D effort. National organizations, like the New Energy and Industrial Technology Development Organization (NEDO) in Japan, Megavind in Denmark, and the Mexican Centre for Innovation in Wind Energy (CEMIE-Eólico) serve as hubs to foster collaboration in wind R&D.

The European Technology and Innovation Platform on Wind Energy (ETIP Wind) has facilitated the collaborative research effort across Europe. It is vital that the wind industry and the national governments continue supporting wind energy R&D activities, as wind is a substantial contributor to a sustainable energy mix.

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

Country	Facility Description
Offshore wind test and demonstrations sites	
Belgium	OCAS fatigue testing facility for welding seams in offshore substructures
Denmark	Four new test sites added at Høvsøre and Østerild; turbines up to 330 m may be tested at Østerild
Finland	A 42-MW demonstration offshore wind farm at a Baltic Sea site with winter ice began operations in 2017
France	Floating wind demonstration projects awarded in 2016 continue to progress: • Floatgen was inaugurated and tested along the quay of Saint-Nazaire: a floating offshore demonstrator featuring an innovative “damping pool” concrete floating substructure and a 2-MW Vestas turbine • Faraman: three Siemens 8-MW on tension-leg platforms • Groix-and Belle- Ile: four GE Haliade 6-MW turbines mounted on a floater • EoldMed: four Senvion 6.15-MW turbines in the IDEOL “damping pool” concrete floating substructure • Leucate: three GE Haliade 6-MW turbines mounted on a floater
Ireland	The Galway Bay Marine and Renewable Energy Test Site will engage in marine energy research including floating offshore wind. It will be used to test BluWind, a floating wind 1:6 scale prototype demonstrator
Japan	A new floating offshore demonstrator commenced operations in the Fukushima FORWARD offshore wind farm, namely a Hitachi 5-MW downwind turbine with an advanced spar-type floater
Spain	PLOCAN (Canary Islands) and BiMEP (Biscay) are research facilities for testing marine energies
United Kingdom	Statoil installed the world’s first floating grid-connected offshore wind park, the 30-MW Hywind pilot. The Blyth Offshore Demonstration site featured five MHI-Vestas 8.3MW turbines mounted on float-and-sink gravity-based foundations
United States	Two offshore wind pilots are under development: Icebreaker project with six 3.45-MW, direct-drive turbines on mono bucket foundations in Lake Erie. The Aqua Ventus I project, a pilot floating offshore wind farm with two 6-MW direct-drive turbines on concrete, semisubmersible foundations in Maine
Land-based test and demonstration sites	
Canada	WEICan 10-MW test site including energy storage demonstrated secondary frequency regulation
Ireland	Eirgrid, the Irish TSO, completed trials in 2017 to verify the capabilities to provide newly defined system services. Wind power plant qualified to provide Fast Frequency Response (FFR) and Primary Operating Reserve (POR) among other services
Sweden	Rise Research Institutes of Sweden and Skellefteå Kraft are working to establish a test center aimed at testing wind turbines and other equipment in cold and icy conditions
China	China General Certification Center successfully tested an 83.6-m blade (natural frequencies and static testing)
Denmark	A new large scale-facility at DTU is in operation as part of Villum Center for Advanced Structural and Material Testing
México	A blade manufacturing laboratory and a test facility for small blades are available through the CEMIE-Eólico
Spain	WINDBOX, a test facility under construction will incorporate five test benches: hydraulic pitch test, generator slipping rings test, blade and hub bearings test, yaw system test, and specific junctions test
United Kingdom	The Blade Erosion Test Rig (BETR) facility was commissioned by ORE Catapult
Climatic testing facilities	
Belgium	Climatic test chamber (OWI-lab) and the cold climate wind tunnel (VKI)
Canada	Nergica (formerly TechnoCentre Eolien) cold climate modeling, measurement, and forecasting tests in its R&D program
Finland	An Icing Wind Tunnel for testing of instruments and materials in representative icing conditions
Germany	HiPE-Wind, a climatic chamber used to test 10-MW wind turbine converter components with the goal of extending service life and preventing failures (University of Bremen and Fraunhofer IWES)
Wind tunnels and wave tanks	
Denmark	A new wind tunnel is under construction
Italy	CNR-INSEAN wave tank and circulating water channel tests model-scale offshore wind turbines installed on a floating platform in a controlled environment. POLI-Wind tunnel actively controls wind turbine models to simulate wind farms
Germany	Testing and developing of maritime technologies under realistic environmental conditions in regard to wave current soil interaction takes place in the Large Wave Flume in Hannover, a significantly extended, large-scale test facility. Testing includes analyses of substructures of offshore wind turbines, hydroelectric power, and wave/tidal energy systems
Wind resource assessment	
Belgium	A new floating lidar (FLiDAR) system is available at OWI-lab
Ireland	Two new meteorological Lidars were installed in 2017
Norway	A floating Lidar buoy was developed by NOWITECH and Fugro
More comprehensive data on test facilities can be found in the US DOE’s *Wind Energy Facilities Book 2017* and in *Catalogue of Facilities Available*, published by EU FP7-project IRPWIND (www.irpwind.eu/publications/deliverables)	

Table 9. National Statistics of the IEA Wind Member Countries 2017

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	2.8	196	8.0	75	10.6%
Belgium	2.8	473	6.3	84	7.6%
Canada	12.2	341	30.7	585	5.2%
China	188.4	19,659	305.7	6,308	4.8%
Denmark	5.5	274	14.7	34	43.3%
Finland	2.0	513	4.8	86	5.6%
France	13.5	1,665	22.6	471	4.8%
Germany	55.9	6,290	106.6	603	17.7%
Greece	2.7	282	4.2	51	8.3%
Ireland	3.4	568	7.4	30	24.8%
Italy	9.5	254	17.5	320	5.5%
Japan	3.4	169	5.8	906	0.6%
Korea	1.2	130	1.7	561	0.3%
México	3.9	415	11.2	310	3.6%
Netherlands	4.2	-56	10.6	120	8.8%
Norway	1.2	315	2.9	134	2.1%
Portugal	5.3	0	12.3	51	24.0%
Spain	23.1	81	47.9	268	18.2%
Sweden	6.7	196	17.6	141	12.5%
Switzerland	0.1	0	0.1	58	0.2%
United Kingdom	19.8	3,619	49.6	350	14.2%
United States	89.0	6,974	254.3	4,015	6.3%
Totals	**456.6**	**42,358**	**943**	**15,560**	**6.1%**
Non-IEA Wind TCP countries	82.5*	9,992*	488*	9,958*	1.9%*
World Total	**539.1** [1]	**52,500**	**1,430***	**25,518***	**5.6%** [2]

* Estimates

Table 10. Potential Capacity Increases Beyond 2017 in Reporting Member Countries

Country	Planning Approval[a] (MW)		Under Construction[b] (MW)		Total (MW)
	Land-based	Offshore	Land-based	Offshore	
Canada	1,995	---	624	---	2,619
Denmark	---	350	---	1,006	1,356
Finland	2,000	820	---	---	2,820
France	2,144	---	---	---	2,144
Germany	1,714	---	---	780	2,494
Ireland	678	---	---	---	678
México	5	---	24	---	29
Norway	5,512	---	1,630	---	7,142
Portugal	123	25	---	---	148
Spain	4,107	---	---	---	4,107
Sweden	7,817	2,401	2,395	---	12,613
United States	---	---	28,668	24	28,692

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

Table 11. Targets Reported for IEA Wind TCP Member Countries

Country	Official Target Renewable Energy Sources (RES)	Official Target Wind (2017)	2017 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	2,828 MW*
Belgium	13% RES share in final gross energy consumption by 2020	Offshore: 2,741 MW; Land-based: 3,000 MW by 2020	2,370 MW (Offshore: 712 MW Land-based: 1,658 MW)
China	680 GW by 2020	210 GW by 2020	188 GW
Denmark	30% by 2020, 50% by 2030; independent of fossil fuels by 2050	50% by 2020	43.3%
European Union	20% of energy demand by 2020; 1,206 TWh of renewable electricity by 2020	486 TWh by 2020	---
Finland	39% by 2020	6-6.5 TWh/yr by 2020	4.8 TWh
France	---	Land-based: 15 GW by 2018; Offshore: 0.5 GW by 2018	Land-based: 13.488 GW
Germany	80% share of all renewable energies of gross electricity consumption by 2050. Intermediate targets of 40-45% share by 2025 and 55-60% by 2035	Land-based: 2.8 GW/yr 2017-2019; 2.9 GW/yr from 2020 and beyond Offshore: 6.6 GW by 2020 and 15 GW by 2030	55,876 MW; 17.7%; 106.6 TWh
Ireland	16% of total energy demand by 2020, projected 40% of electricity demand	---	---
Italy	17% by 2021	Land-based: 12 GW, Offshore: 0.68 GW by 2021	Land-based: 9,496 MW
Japan	22-24% by 2030	10 GW by 2030	3,399 MW
Korea	0.03	0.9% by 2020	0.3%
México	18,406 MW by 2017 (PRODESEN 2017-2031)	4,329 MW by 2017 (Prospectiva ER´s 2017-2031), 12.8 GW by 2020	3,942 MW
Netherlands	14% RES by 2021	---	---
Norway	28 TWh/yr by 2020	---	---
Portugal	31% of final energy consumption by 2020	Land-based: 5,300 MW; Offshore: 0.027 GW by 2020	5,313 MW
Spain	20% RES by 2020	6.4 GW added by 2020	---
Sweden	50% RES by 2020	30 TWh by 2020	17.6 TWh
Switzerland	Increase generation by 22.6 TWh by 2050	0.6 TWh by 2020, 4 TWh by 2050	0.1 TWh
United Kingdom	30% of electricity from RES by 2020	No specific target, forecast 20 GW by 2020	---
United States	Increase generation of electric power from renewables through cost reductions	Reduce the cost of land-based to $0.031/kWh (0.026 EUR/kWh) without incentives and reduce the modeled cost of offshore to $0.093/kWh (0.078 EUR/kWh) by 2030	---

--- No official target available
*Data from WindEurope statistics 2017

References

Opening photo: The ELISA-ELICAN Project in Spain; A self-buoyant precast concrete telescopic tower and foundation for installation of offshore wind turbines without the help of crane ships (Photo credit: ESTEYCO)

[1] GWEC (2018). *Global Wind Report 2017*

[2] REN21 (2018). *Renewables 2018 Global Status Report*

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

ACTIVITIES OF THE IEA WIND TCP

Figure 1. Participants at IEA Wind TCP ExCo 79, Espoo, Finland

RESEARCH TASKS & STRATEGIC PRIORITIES

The International Energy Agency Wind Technology Collaboration Programme (IEA Wind TCP) is a collaborative venture operating under the auspices of the IEA. Formally known as the Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems, the TCP is comprised of 26 contracting parties from 21 Member Countries, the Chinese Wind Energy Association (CWEA), the European Commission, and WindEurope (Italy and Norway each have two contracting parties).

Since 1977, participants have developed and deployed wind energy technology through vigorous national programs and international efforts. Participants continue to exchange information on current and future activities at semi-annual meetings and participate in co-operative research tasks.

In 2017, the IEA Wind TCP had 16 active Tasks working on wind energy research, development, and deployment (R,D&D). These co-operative 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. Through these activities, the IEA Wind TCP Member Countries leverage national efforts to complete larger and more complex projects than an individual organization could complete.

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 2 shows the timelines for the ongoing research tasks and their alignment with the TCP's priority areas. In 2017, Task 39 Quiet Wind Turbine Technologies and Task 40 Downwind Turbine Technologies were approved, and will begin work in 2018. Task 35 Full-Size Ground Testing for Wind Turbines and Their Components concluded at the end of 2017.

The IEA Wind TCP's activities throughout 2017 aligned with the TCP's Strategic Plan. Tasks aimed 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.

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	x			x	11, 19, 27, 31, 32, 36
2: Wind Power Technology	x		x	x	11, 19, 26, 27, 29, 30, 35, 39, 40
3: Wind Integration	x	x		x	11, 25, 37
4: Social, Educational, and Environmental Issues	x		x	x	11, 26, 27, 28, 34, 39
5: Communications			x	x	All

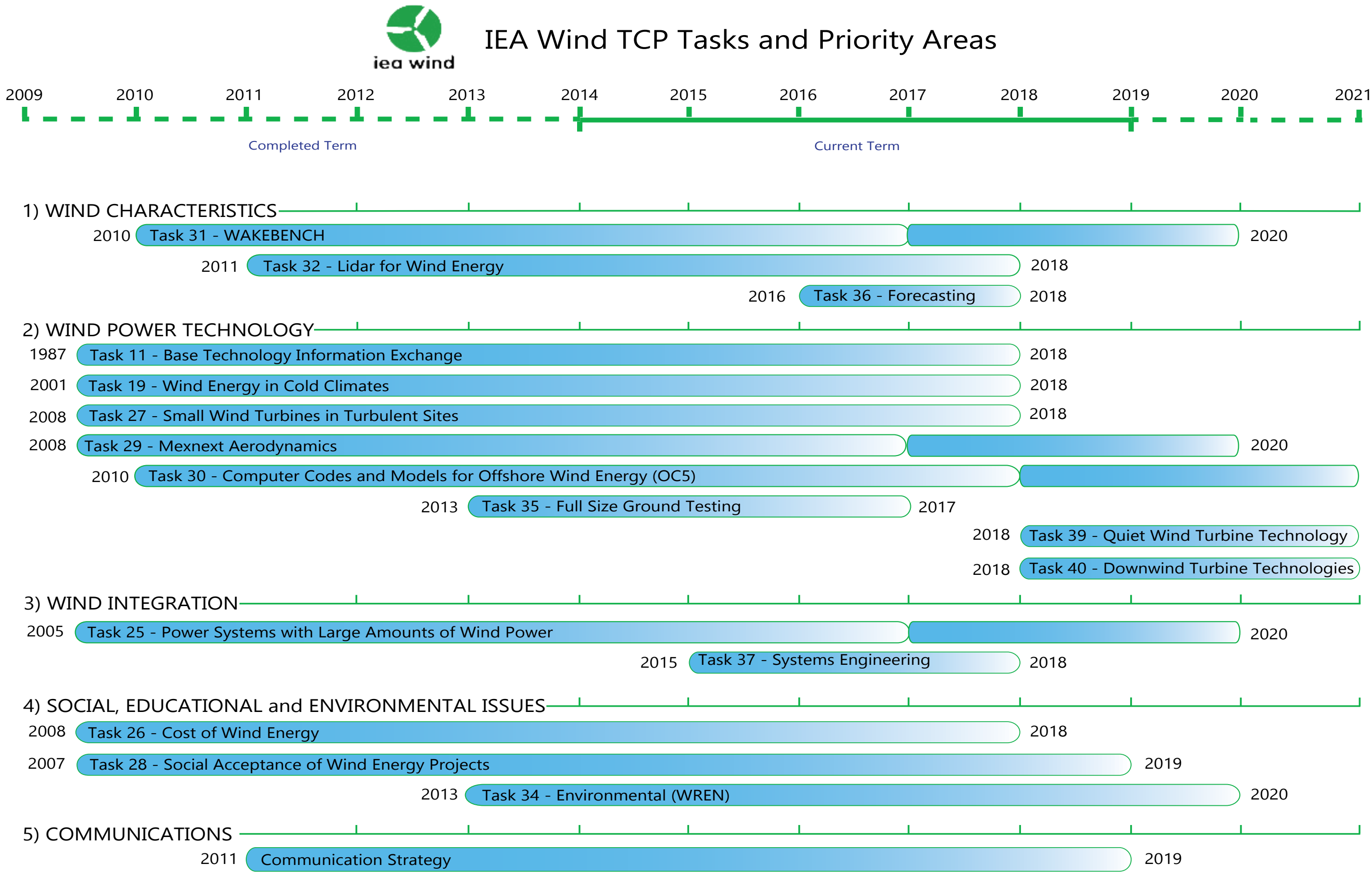

Figure 2. Priority areas from IEA Wind TCP Strategic Plan and active research tasks

TASK PARTICIPATION

In 2017, each Task had between 5 to 18 participating countries working on issues related to wind energy technology and deployment; new Tasks 39 (Quiet Wind Turbine Technology) and 40 (Downwind Turbine Technologies) are expected to begin work in 2018 (Table 2). The combined effort devoted to a Task allows a country to leverage its research resources and collaboratively address complex wind research challenges.

The IEA Wind TCP ExCo approves and oversees each research Task. New Tasks are added to the IEA Wind TCP as Member Countries agree on new co-operative research topics. For each Task, the participating countries jointly develop a work plan, which is reviewed and approved by the full IEA Wind TCP. Often, a participation fee from member countries supports the OA's efforts to coordinate the research and report to the Executive Committee (ExCo).

Participating countries and sponsor members join Tasks that are most relevant to their national research and development programs. Organizations within a member country and sponsor members are welcome to participate in research Tasks. See Appendix A of this report for additional information.

RESEARCH TASK ACTIVITIES

In 2017, a total of 279 organizations contributed to the 16 active IEA Wind TCP Tasks. Through the Tasks, these organizations participated in 41 workshops and events, and produced 49 deliverables including recommended practices, datasets, reports, and papers.

Contributing organizations represent a cross section of the wind energy sector, including 13 utilities, nine Transmission System Operators, eight certification bodies, 22 governmental organizations, 10 sectoral organizations, 69 wind industry suppliers, 65 Universities, and 71 Research Organizations. Also, the 12 participating wind turbine manufacturers represent more than 67% of the world cumulative wind capacity.

The IEA Wind TCP made significant progress on several collaborative research efforts in 2017, including publication of following publicly-available reports and tools:

- Task 26—Wind Projects Statistics Data Viewer
- Task 29—Wind Turbine Noise Measurements in Controlled Conditions (*International Journal of Aero-Acoustics*)
- Task 26—*Impacts of Wind Turbine Technology of the System Value of Wind in Europe*
- Task 31—*GABLS3 Benchmark Open Science Benchmarking Data and Results*

Three Recommended Practices (RP) were published in 2017:

- *RP 13 Ed 2: Wind Energy Projects in Cold Climates* (Task 19)
- *RP 17: Wind Farm Data Collection and Reliability Assessment for O&M Optimization* (Task 33)
- *RP 18: Floating Lidar Systems* (Task 32)

Table 2. Member Participation in Research Tasks During 2017

Participant	Research Task Number															
	11	**19**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**34**	**35**	**36**	**37**	**39**	**40**
Austria		x			x					x			x			
Belgium		x														
Canada		x	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	OA	x		
European Commission				x												
Finland	x	OA	OA			x							x			
France			x				x	x	x	x	x		x			
Germany	x	x	x	x		x	x	x	x	OA		OA	x	x		
Greece																
Ireland	x		x	x	x	OA					x		x		OA	
Italy	x		x					x								
Japan	x		x	x	x	x		x	x	x						OA
Korea					x			x		x						
México	x		x													
Netherlands	x		x	x			OA	x	x	x	x			x		
Norway	x	x	x	x			x	x		x	x		x	x		
Portugal			x			x		x			x		x			
Spain	x		x		OA		x	x	OA		x		x	x		
Sweden	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		
United States	x		x	OA	x	x	x	OA	x	x	OA	x	x	OA		x
WindEurope			x													
Totals	**15**	**11**	**18**	**10**	**7**	**8**	**9**	**13**	**10**	**12**	**11**	**5**	**13**	**8**	**1**	**2**

Note: OA indicates Operating Agent that manages the Task; for the latest participation data, check the Task websites.

RESEARCH TASK ACTIVITIES CONTINUED

Task participants presented research findings, held workshops and webinars, and published conference papers and journal articles throughout the year. Final reports, technical reports, research plans, and Recommended Practices produced by the tasks are available at community.ieawind.org. For more information about the ongoing co-operative research activities, contact the Task OA listed in each Task chapter or Appendix B of this report.

Task 11 Base Technology Information Exchange promotes and disseminates knowledge on emerging wind energy topics. This is accomplished through Topical Expert Meetings (TEMs) and Recommended Practices (RPs), which serve as the basis for both international and national standards. During 2017, Task 11 organized three TEMs and published three RPs:

- *RP 13 Edition 2: Wind Energy Projects in Cold Climates*
- *RP 17: Wind Farm Data Collection and Reliability Assessment for O&M Optimization*
- *RP 18: Floating Lidar Systems*

Task 19 Wind Energy in Cold Climates enables large-scale deployment of cold climate wind power in a safe and economically feasible manner through standardization and recommended practices. Task participants updated a cold climate wind power market study for 2015-2020 in WindPower Monthly magazine and published *RP 13 Ed 2: Wind Energy Projects in Cold Climates* in 2017. Further, the Task is working towards including cold climate aspects in the IEC standard 61400-15, Edition 1 "Site Energy Yield Assessment," developing and publishing warranty guidelines for wind turbines equipped with anti- or de-icing solutions for turbine testing purposes, and international ice throw guidelines for project development purposes.

Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power provides information that facilitates economically feasible wind energy penetration in electricity power systems. In this final year of the three-year term, the Task completed a second edition of *RP 16* for integration studies, which now includes solar photovoltaics (published in August 2018), as well as numerous journal articles and case studies to bring best practice wind integration experience, study methods, and results to member countries and a global audience. In addition, the fact sheets and integration study database have been updated. A summary report of the latest integration study results and experience will be published in 2018.

Task 26 Cost of Wind Energy aims to understand past and present wind energy cost trends and anticipate future trends using consistent, transparent methodologies and information on the cost of wind energy. In 2017, Task 26 developed an interactive online data viewer for land-based wind project-level cost statistics, as well as a report assessing the impacts of turbine technology on the system value of wind energy in Europe.

Task 27 Small Wind Turbines in High Turbulent Sites continues to develop technical recommendations for the fourth revision of the IEC 61400-2 standard and is finalizing a Recommended Practice on micro-siting of small wind turbines. Additionally, a compilation of country case studies documenting computational fluid dynamics (CFD)modeling, measurements results, and modeling and testing efforts conducted within the scope of Task 27 is near completion.

Task 28 Social Acceptance of Wind Energy Projects began a new phase in 2017. Task participants identified the following priorities for phase III: increasing knowledge sharing, researching methods that will help industry work effectively with the public, and developing training practices for community engagement.

Task 29 Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models concluded a three-year term aimed at improving aerodynamic models used for wind turbine design through rigorous comparison of the New MEXICO experimental data and calculated measurements. The Task's work is summarized in the publication of 15 journal articles, reports, and presentations on wind turbine aerodynamics and improvements to aerodynamic models used for wind turbine design.

Task 30 Offshore Code Comparison Collaboration Continued, with Correlation (OC5) was initiated to validate offshore wind modeling tools through the comparison of simulated responses to physical response data from actual measurements. Phase III of the project started in 2017 and focuses on model verification and validation using data from the full-scale, open-ocean alpha ventus project—the first German offshore wind farm.

Task 31 Wakebench: Verification, Validation, and Uncertainty Quantification of Wind Farm Flow Models aims to develop an international verification and validation (V&V) framework that will support a sustained improvement of wind farm models using an integrated approach resulting in more comprehensive characterization of modeling systems. The framework facilitates a continuous evaluation process, simulating as many test cases as possible to gain confidence and credibility in the model results. The ultimate goal is to minimize uncertainty and avoid wind plant performance over prediction.

Task 32 Wind Lidar Systems for Wind Energy Deployment identified and mitigated barriers to the use of lidar technology as a remote sensing alternative to traditional wind measurements techniques. The task addresses site assessment, power performance, loads and control, and complex flow through workshops and international forums, where industrial and academic partners exchange new ideas, experiences, and measurement techniques for using lidar in wind energy. In 2017, participants published IEA Wind TCP Recommended Practices 18: Floating Lidar Systems.

Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN) is a collaborative forum where products are developed to better understand the environmental issues with wind energy and demonstrate solutions for wildlife challenges. Task-developed information and materials are disseminated through WREN Hub (https://tethys.pnnl.gov/about-wren), including white papers and ongoing outreach and engagement via a range of activities.

Task 35 Full-Size Ground Testing of Wind Turbines and their Components worked to develop recommendations to standardize full-size ground testing procedures for rotor blades and nacelles across test facilities around the world. Task participants developed a consortium of testing facilities to begin standardizing test procedures to provide equivalent results at the same confidence level. The Task published a technical report on nacelle testing in 2017 and a technical report covering blade testing is planned for 2018.

Task 36 Forecasting for Wind Energy focuses on improving the value of wind energy forecasts by improving meteorological wind speed forecasts and power conversion steps usually done by forecast vendors, as well as facilitating better use of the forecasts. Task participants are preparing an IEA Wind TCP Recommended Practice on how to select the optimum forecast solution and set up a benchmarking process, as well as publications for the scientific and engineering communities to serve as reference materials for the recommended practices guidelines and for further study of wind power forecasting.

Task 37 Wind Energy Systems Engineering: Integrated Research, Design, and Development began working on three Work Packages in 2016: 1.) guidelines for a common framework for integrated RD&D at different fidelity levels, 2.) reference wind energy systems, and 3.) benchmarking multidisciplinary design, analysis, and optimization (MDAO) activities at different system levels (both turbines and plants). Significant progress has been made in each work package with the development of a wind turbine and plant ontology to standardize modeling interfaces for MDAO; two reference turbine designs (technical report expected in 2018); as well as a single-discipline aerodynamics optimization case study.

Task 39 Quiet Wind Turbine Technology held its kick-off meeting to develop a detailed work plan. The group intends to focus in three areas: interdisciplinary education and guidance, aspects of technical noise, and the development of a Recommended Practice.

Task 40 Downwind Turbine Technologies is coordinating international research to investigate the advantages of downwind turbine technologies in certain installation conditions. The Task expects to publish an IEA Wind TCP Recommended Practice on downwind turbine technologies, as well as journal and conference papers that include participation from industry and other end-user organizations.

TASK 11
BASE TECHNOLGY INFORMATION EXCHANGE

Task 11 Contact and Information

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INTRODUCTION

Task 11 of the IEA Wind Technology Collaboration Programme (TCP) promotes and disseminates knowledge on emerging wind energy topics. This is accomplished through Topical Expert Meetings (TEMs), in which invited experts meet to exchange information on R&D topics of common interest to the IEA Wind TCP members. Task 11 also disseminates knowledge by developing IEA Wind TCP Recommended Practices. Many IEA Wind Recommended Practices documents have served as the basis for both international and national standards.

Nearly every country of the agreement participates in this Task, which has been part of the IEA Wind TCP since 1978. Task 11 allows members to react quickly to new technical and scientific developments and information needs.

Task 11 reports and activities bring the latest knowledge to wind energy experts in the member countries and offer recommendations for the future work of the TCP. Task 11 is also a catalyst for starting new IEA Wind TCP research Tasks.

PROGRESS & ACHIEVEMENTS

Topical Expert Meetings

TEMs are conducted as workshops, where information is presented and discussed in an open manner. Generally, oral presentations are expected from all participants.

Topical Expert Meetings – A vehicle for V&V collaboration

As a community of wind energy experts, the IEA Wind TCP values collaboration between different Tasks. During TEM 88 on Verification and Validation between Data, High-Fidelity Models, and Engineering Models, presenters highlighted several areas of collaboration: rotor aero-elastics (Task 29), offshore hydrodynamics (Task 30), and wind-plant aerodynamics (Task 31).

The TEM focused on computationally-efficient engineering tools that can support iterative and probabilistic design process and optimization. These tools allow for great advances in wind energy technology; however, in practice, simplifying assumptions brings limitations. Therefore, verification and validation (V&V) is key to their accuracy and the meeting's purpose was to share V&V experiences.

Another output of the meeting was a discussion on establishing future IEA Wind TCP V&V collaboration. As the three related Tasks end in 2017 or 2018, the group decided to begin working on proposals for extension.

Meeting proceedings are made available to Task 11 participating countries immediately and to the public one year later. Three TEMs were held in 2017:

TEM 87 on Smart Blades: DTU (Technical University of Denmark) hosted TEM 87 on April 27-28. Twenty-five participants from six countries (Denmark, Germany, Italy, the Netherlands, Switzerland, and the United States) attended the meeting. Participants received an overview of SMART blade technology, including the status of research and development activities and areas that need new research initiatives.

TEM 88 on Three-Way Verification and Validation between Data, High-Fidelity Models, And Engineering Models: ORE Catapult and NREL co-hosted TEM 88 in ORE Catapult's Scotland facilities from September 6-9. It was attended by 32 participants from nine countries (Denmark, France, Germany, the Netherlands, Norway, Spain, Switzerland, the United Kingdom, and the United States). This meeting shared V&V experiences and discussed pathways and priorities for future IEA Wind TCP V&V collaboration.

TEM 89 on Next Grand Vision for Wind Energy—Next Technology and Infrastructure Challenges to Realize Wind's Full Potential: NREL hosted TEM 89 in its facilities on October 22-23. It was attended by 48 participants from 11 countries (China, Denmark, France, Germany, Italy, Norway, Spain, Sweden, Switzerland, the United Kingdom, and the United States). This meeting aimed to develop a global agenda to move toward wind technology as a primary

Figure 1. Participants at TEM 89 Next Grand Vision for Wind Energy: Next Technology and Infrastructure Challenges to Realize Wind's Full Potential

electricity generation option, which should serve as the basis for the redefinition of IEA Wind's Strategic Plan. Two follow-up meetings continued the work started during TEM 89: the Task 25 meeting and the first day of the ExCo meeting in México.

Recommended Practices

Another activity of Task 11 is to develop IEA Wind TCP Recommended Practices (RP). RPs originate from research Tasks and are drafted by their participants, often as a final deliverable of the Task's workplan. Three Recommended Practices (RP) were reviewed and published in 2017:

- *RP 13 Ed.2: Wind Energy Projects in Cold Climates* (Task 19)
- *RP 17: Wind Farm Data Collection & Reliability Assessment for O&M Optimization* (Task 33)
- *RP18: Floating Lidar Systems* (Task 32 in coordination with the Offshore Wind Accelerator initiative)

Expert Community Platform

The objective of Task 11 is to promote wind energy through information exchange among experts on research, technology, and innovation topics of common interest. Task 11 serves as a contact point for experts interested in IEA Wind TCP activities. To that end, the new IEA Wind website and expert community platform was up and running in November 2017 (community.ieawind.org/home).

One very important feature of the platform is the ability to create subgroups (or communities) of experts around specific topics. For example, these groups may regroup all participants of a specific meeting (such as a TEM) and give them a dedicated space on the platform, including a discussion forum and a library where they can store all relevant documents for the group in a centralized manner.

OUTCOMES & SIGNIFICANCE

Task 11 can be seen as the backbone of the IEA Wind TCP's activities. As already mentioned, one of Task 11's goals is to hold TEMs on different wind energy research topics. Active researchers and experts from participating countries are invited to attend these meetings. Meeting topics, selected by the IEA Wind TCP Executive Committee, have covered the most important wind energy issues for decades.

A TEM can also begin the process of organizing new research Tasks. In 2017, the participants of TEM 87 on Smart Blades agreed to initiate the process of starting a new task. Three countries (Denmark, Germany, and the Netherlands) have been committed to lead the process. In collaboration with IEA Wind TCP's Secretariat, Task 11 coordinates the review and approval process by the Executive Committee.

Table 1. Task 11 Participants in 2017

Member/Sponsor	Participating Organizations
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	New Energy and Industrial Technology Development Organization (NEDO)
México	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)

IEA Wind has issued 19 IEA Wind Recommended Practices, and many of these documents have served as the basis for both international and national standards.

NEXT STEPS

The TEM topics selected for 2018 are:

- TEM 90: Distributed Wind, hosted by DTU in March 2018
- TEM 91: Blade Durability, hosted by MSU in June 2018
- TEM 92: likely on wind energy and digitalization

In 2018, Task 11 will continue to implement the IEA Wind TCP online community website. The chosen platform provider offers a highly flexible product with numerous functionalities that can be adapted to the TCP's needs in order to foster members' engagement and maximize benefits.

References

Opening photo: Chur, Switzerland, Suisse Eole picture contest (Photo credit: Susanne Baumberger)

Authors: Lionel Perret and Nadine Mounir, Planair SA, Switzerland.

TASK 19
WIND ENERGY IN COLD CLIMATES

Task 19 Contact and Information

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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, turbine icing and low ambient temperatures still present 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) and recent research.

IEA Wind TCP Task 19 aims 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 during working period 2016-2018 include:

- Publish a cold climate wind power market study update for 2015-2020 in *WindPower Monthly* magazine [1]
- Include cold climate aspects in International Electrotechnical Commission (IEC) standard 61400-15, Edition 1 "Site Energy Yield Assessment"
- Validate and further develop T19IceLossMethod, a free software for calculating icing losses from standard turbine SCADA data
- Develop and publish warranty guidelines for wind turbines in icing climates (equipped with anti- or de-icing solutions) for turbine testing purposes
- Develop and publish international ice throw guidelines for project development purposes
- Update the *Available Technologies* report and *RP 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 the wind energy sector.

PROGRESS & ACHIEVEMENTS

In 2017, the Task made progress on two high-priority deliverables: warranty guidelines for wind turbines in icing climates and the international ice throw guidelines.

Table 1. Task 19 Participants in 2017

Member/Sponsor	Participating Organizations
Austria	Energiewerkstatt Verein
Belgium	OWI-LAB
Canada	Technocentre éolien
CWEA	Chinese Wind Energy Association (CWEA)
Denmark	Technical University of Denmark Wind Energy
Finland	VTT Technical Research Centre of Finland
Germany	Fraunhofer Institute for Energy Economics and Energy System Technology (IEE)
Norway	Kjeller Vindteknikk
Sweden	WindREN
Switzerland	Meteotest
United Kingdom	DNV GL

The warranty guidelines report is focused on turbines equipped with active Ice Protection Systems (IPS) – anti- or de-icing solutions that mitigate ice build-up using electrothermal mats on blades or hot air fans inside blades. These guidelines provide advice on potential warranty tests that verify IPS performance, so cold climate industry can quickly develop new solutions.

In February 2017, Task 19 organized a kick-off event for the WinterWind 2017 conference: an industry workshop for owner/operator/developers and consultants. This workshop focused on turbine level performance (e.g., warranties on "winter power curves") and provided valuable industry input to the guidelines. By June, the Task had formulated draft guidelines; several wind turbine manufacturers and third-party IPS providers reviewed the draft and offered comments.

The international ice throw guidelines expert group, which consists of Task 19 members and external industry participants, gathers the best knowledge around this specific subject. A kick-off meeting was arranged in Vienna in April

Figure 1. Task 19 logo (Graphic credit: DNV GL)

2017 to develop international best practices for evaluating the risk of ice throw on personnel and infrastructure for project planning applications. These guidelines are recommended for international implementation.

In 2017, Task 19 communicated results and progress in the following ways:

- Two workshops and eight presentations on warranty guidelines for wind turbines in icing climates and ice throw at the WinterWind 2017 conference in Skellefteå, Sweden
- Presentation: "Overview of IEA Wind Tasks – IEA Task 19 Wind Energy in Cold Climates" at Vaasa Wind Exchange conference and exhibitions in Finland
- Chairing the *WindPower Monthly* Optimizing Wind Farms in Cold Climates conference in Antwerp, (October 2017) as well as a Task 19 panel and two presentations
- "Mitigating ice throw risks" session, three general presentations, and two posters at WindEurope conference in Amsterdam, the Netherlands
- *Recommended Practice 13 Ed 2: Wind energy Projects in Cold Climates* published Feb. 2017
- Several LinkedIn and Twitter posts by Operating Agent

Performance Warranty Guidelines for Wind Turbines in Icing Climates

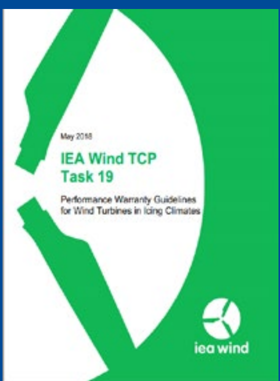

Figure 2. Task 19's Performance Warranty Guidelines for Wind Turbines in Icing Climates, May 2018

Over 25 companies around the world, ranging from owner/operator/developers to energy consultants, turbine manufacturers, and component suppliers, have helped outline and offered comments on the *Performance Warranty Guidelines for Wind Turbines in Icing Climates.*

Their input substantially facilitated and accelerated the implementation of the guidelines as industry best practices. These guidelines will also enable the accelerated development of new and better Ice Protection Systems for wind energy markets.

With the efforts of Task 19, development of wind farms in cold climates will be substantially more affordable and safe.

OUTCOMES & 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 on standardization and recommended practices.

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

NEXT STEPS

In 2018, Task 19 plans to:

- Publish *Performance Warranty Guidelines for Wind Turbines in Icing Climates*
- Publish *International ice throw guidelines*
- Publish updated *Available Technologies* report
- Publish updated T19IceLossMethod free software
- Prepare extension proposal for 2019-2021
- Advance work in IEC 61400-15 standard
- Arrange an online user meeting for T19IceLossMethod free software users
- Increase e-dissemination via social media, website and email newsletters

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)

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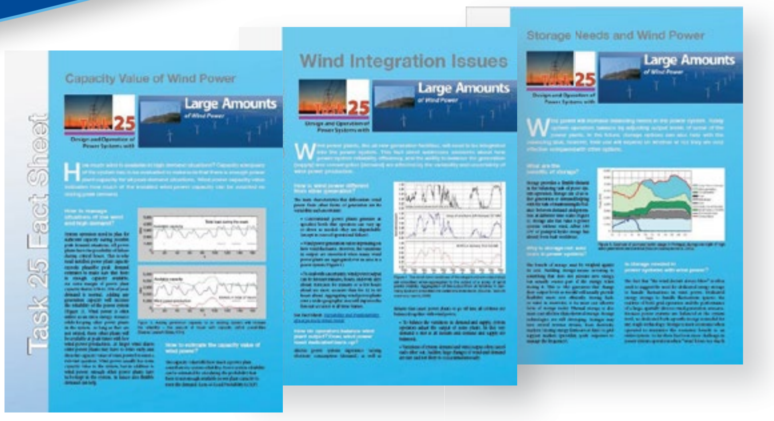
Author: Ville Lehtomäki, VTT Technical Research Centre of Finland, Finland.

TASK 25

DESIGN AND OPERATION OF POWER SYSTEMS WITH LARGE AMOUNTS OF WIND POWER



Task 25 Contact and Information

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INTRODUCTION

Wind integration studies are important measures to ensure that power systems can accommodate expected amounts of wind power. However, different countries use different methodologies, data, and tools, as well as different terminology and metrics, to represent the results, making it difficult to compare integration study results. Therefore, it is important that each country apply commonly-accepted standard methodologies.

The IEA Wind TCP Task 25 analyzes and develops methodologies that assess the impact of wind power on power systems. This information facilitates economically feasible wind energy penetration in electricity power systems worldwide. 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).

One of the target groups of Task work is power system operators. System operators for Denmark, France, Italy, and México were directly participating in Task 25 work in 2017, as well as the Utility Variable Generation Integration Group (UVIG) from the United States. Presentations from the work of the European body for Transmission System Operators (ENTSO-E) were also given in Task meetings.

PROGRESS & ACHIEVEMENTS

Task 25 has established an international forum for member countries and Transmission System Operators (TSOs) to exchange knowledge of and experiences with power system operations with large amounts of wind power.

The Sustainable Energy Authority of Ireland (SEAI) hosted the 2017 spring Task meeting in Dublin, Ireland, as well as a public event on grid integration challenges in Dublin. Instituto Nacional de Electricidad y Energias Limpias (INEEL) hosted the autumn meeting in Cuernavaca, México.

In 2017, the Task collaborated with the IEA (GIVAR project) on *Getting Wind and Sun onto the Grid: A Practical Manual for Policy Makers* and reviewed both the *Status Report on Power System Transformation of IEA* and IRENA's report on integration of variable renewable generation in islands. In October, Task 25 and IEA PVPS Task 14 organized a common session on Recommended Practices (RP) for the Berlin Wind Integration Workshop.

Task 25 published revised fact sheets (opening figure) and updated their wind power time series database in 2017. Collaboration with IEA PVPS Task 14 resulted in a thorough update of *RP 16: Wind Integration Studies* (originally published in 2013). The following collaborative articles were published in 2017:

- *Wind Power within European Grid Codes: Evolution, Status and Outlook* [1]
- *Comparison of Integration Studies of 30-40 Percent Energy Share from Variable Renewable Sources* [2]
- *Recommendations for Wind & Solar Integration Studies* [3]

Wiley's WIREs launched a call for abstracts during 2017 for a special collection on Wind/PV integration studies, with guest editors from Task 25. Altogether, 18 abstracts were accepted for papers on Task 25 activities. Presentations disseminating the work of Task 25 included:

- UCD seminar, Dublin, 27 January 2017 (H.Holttinen)
- Winterwind-17, Skellefteå, 8 February 2017 (H.Holttinen)
- KTH seminar, Stockholm, 16 March 2017 (H.Holttinen)
- Swedish wind power seminar, 3 April 2017 (L.Söder)
- Presentation and poster in Swedish Elkraft conference, Göteborg, 18 May 2017 (H.Holttinen)
- Smart Grid India, invited presentation from Task 25, New Delhi 7 September 2017 (A.Orths/H.Holttinen)
- Norwegian Smart Grid research programme workshop, CINELDI, 20 September 2017 (H.Holttinen)
- WIW2017, workshop session together with IEA and IEA PVPS Task 14, presentation of Recommended Practices, 2017 (H.Holttinen, D.Flynn and K.Ogimoto)
- WindEurope conference poster, Amsterdam, November 2017 (H.Holttinen/D.Fraile)

Wind and Solar Integration Tasks Collaborate on Recommendations for Integration Studies

Recommended Practice 16: Wind Integration Studies has been updated to include solar PV and distribution system studies in collaboration with IEA PVPS Task 14. A complete integration study is usually an iterative process, simulating the power plants in the system and investigating grid and generation capacity adequacy (Figure 1: green boxes). A more detailed level includes dynamic simulations and a flexibility assessment, which are necessary when studying systems with higher shares of wind and solar energy.

Assumptions and parameters, such as investments in the remaining system, are crucial to determine integration impacts and costs. Because system costs are difficult to allocate to any single plant or technology, using total cost comparisons and cost-benefit analysis is preferable. Adding wind and solar energy will reduce total operating costs and emissions as wind and PV replace fossil fuels.

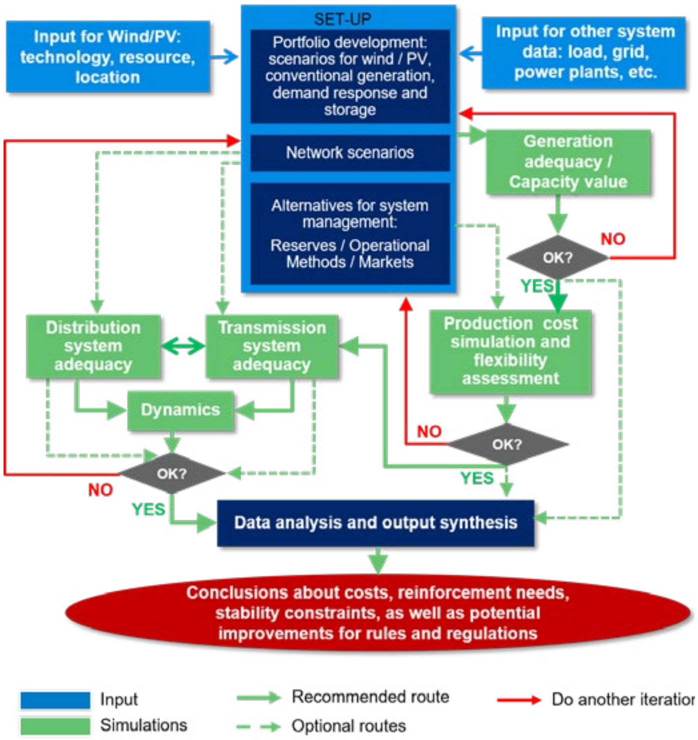

Figure 1. Complete wind/PV integration study flow, showing relevant iteration loops from simulations to set-up and portfolio development, updated for RP 16 Ed 2.

OUTCOMES & SIGNIFICANCE

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. In 2017, Task 25 worked with IEA Paris to reach out to new countries struggling with the first 1-10% share of wind planned in their power system through *Getting Wind and Sun onto the Grid: A Practical Manual for Policy Makers.* The collaboration with IEA PVPS Task 14 resulted in a new Recommended Practice report (Figure 1).

NEXT STEPS

Task 25 will start its fifth phase in 2018, with a new participant joining from South Africa. LNEG will host Task 25 spring 2018 meeting in Lisbon, Portugal, and the fall meeting is planned for Sweden, hosted by KTH. The second edition RP for integration studies, including solar PV, has finished the IEA Wind TCP review process and is expected to be published in the summer of 2018. The summary report of phase four should also be published in 2018. Many national case studies will be published in the *Wiley's WIREs* journal Special Collection.

Table 1. Task 25 Participants in 2017

Member/Sponsor	Participating Organizations
Canada	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	FfE; Fraunhofer IWES; TSO Amprion
Ireland	EnergyReform; University College Dublin (UCD); Sustainable Energy Authority of Ireland
Italy	Transmission System Operator Terna
Japan	Tokyo Univ. of Science; Kyoto Univ.; Central Research Institute of Electric Power Industry (CRIEPI)
México	Instituto Nacional de Electricidad y Energias Limpias (INEEL); TSO CENACE
Netherlands	TSO TenneT; Delft University of Technology
Norway	SINTEF Energy Research
Portugal	Laboratorio Nacional de Energia e Geologia (LNEG); Institute for Systems and Computer Engineering, Technology and Science (InsecTec)
Spain	University of Castilla-La Mancha
Sweden	Royal Institute of Technology (KTH)
United Kingdom	Imperial College; Strathclyde University
United States	National Renewable Energy Laboratory; Utility Variable Generation Integration Group; U.S. Dept. of Energy
WindEurope	WindEurope

Note: IEA Secretariat and IRENA have sent observers to meetings

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Opening figure: Task 25 Wind Integration Fact Sheets (2017).

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TASK 26
COST OF WIND ENERGY

Task 26 Contact and Information

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INTRODUCTION

Wind power generation costs have dropped to a point where they are competitive with conventional generation in some cases. Technology development aims to reduce the cost of energy, but market drivers—like fluctuations in commodity and fuel prices—also impact the cost. Wind energy costs differ among countries, and comparison is difficult.

Task 26 aims to understand past and present wind energy cost trends and to anticipate future trends using consistent, transparent methodologies and information on the cost of wind energy, as well as how wind technology compares to other generation options within the broader electric sector. Phase three began in 2015 and will continue through September 2018. Task participants expect to:

- Enhance international collaboration and coordination regarding the cost of wind energy
- Update data and analysis 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 and 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 2017 (Table 1).

PROGRESS & ACHIEVEMENTS

In 2017, Task 26 focused on land-based wind project-level statistics required for cost of energy calculations in an interactive online data viewer, assessed land-based and offshore wind data and information needed to estimate the cost of offshore wind energy, and published a European electric sector forecast analysis exploring wind turbine technology trends for future electricity system costs and value.

Participants publish updated statistical trends in wind power plant and turbine technology, investment and operating costs, and capacity factors annually on the Task 26 website. A new online tool increases accessibility to the data and permits visualization of trends [1]. These project-level figures can help analysts understand and highlight the differences in technology trends of land-based wind projects over time and in different countries. Building from past work, a report exploring the evolution of cost of land-based wind energy is planned for 2018 [2, 3].

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, compared, and used to develop a baseline representation of the physical characteristics of a typical offshore wind plant [4]. This approach analyzes cost drivers based on information provided by various participants. It represents offshore wind project costs generically to those countries with projects in operation. The Task is preparing a 2018 report that explores offshore wind cost driver differences among countries.

Task 26 uses data and analysis of historic wind energy cost trends to explore projections of the future cost of wind energy [5, 6]. Understanding how wind energy is valued by society and the electricity market, is another area of interest [7].

Table 1. Task 26 Participants in 2017

Member/Sponsor	Participating Organizations
Denmark	Denmark Technical University (DTU); Ea Energy Analyses
European Commission	Joint Research Centre
Germany	Deutsche WindGuard; Fraunhofer IEE
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

Wind Turbine Technology Development's Impact on the Future Market Value of Wind

Task 26 investigates the value of wind energy in the electric sector to understand how wind energy relates to other electricity generation options. A recent publication, based on wind turbine technology trends observable in the online data viewer, explores the impact of advanced wind turbine designs on the European power system development through 2030 [8].

The study focuses on the market value of wind energy and the total system costs resulting from different combinations of wind turbine hub height and specific power (the ratio of the rated generator capacity to the area associated with a rotating wind turbine blade).

Wind turbines with taller towers and larger rotors achieve higher capacity factors and market value: by 2030, advanced turbines can earn as much as 4.3 EUR/MWh (5.2 USD/MWh) more (+13%) than business-as-usual (BaU) technology. High-capacity-factor turbines contribute to lower system costs because of a lower levelized cost of energy and reduced fuel costs for fossil-fuel generators.

However, advanced turbines are a costlier investment per megawatt. Trade-offs between cost and value are required to assess optimal turbine choice, which will vary widely across Europe. Figure 1 shows that advanced wind turbine designs (Ambitious, Likely) increase the value of wind energy in Germany without significant impact on price.

Technology design considerations are important, as failing to consider technology development in land-based wind power when analyzing the evolution of power systems could result in underestimating wind power competitiveness and its potential future electricity sector contribution.

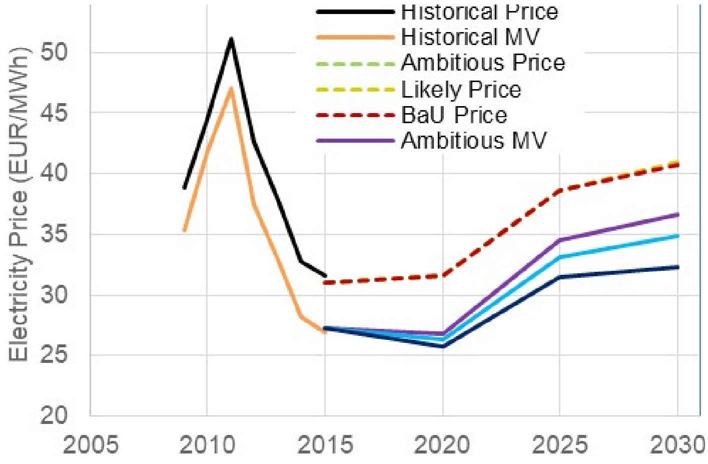

Figure 1. Projection of average prices and market value (MV) of wind in Germany toward 2030 [8]

OUTCOMES & SIGNIFICANCE

Task 26's work aims to inform policy and regulatory communities of the current and future cost of wind energy for land-based and offshore wind technologies. By providing high-quality data that support 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 have used Task 26 wind project cost and performance statistics, and participants regularly use these data for internal and external purposes.

Collaboration 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 offshore wind feasibility. 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.

NEXT STEPS

Task 26 will continue exploring the cost of wind energy by:

- Updating land-based wind project statistics through 2017 accessible through an interactive online data viewer
- Publishing a report discussing the source of changes in cost of land-based wind energy among participating countries from 2008 to 2016.
- Publishing a report discussing the technical and policy-related cost drivers of offshore wind energy, as well as the differences among participating countries

Task 26 participants are developing a work plan for a Task extension from October 2018 through September 2021.

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Opening photo: The 2-MW Gamesa wind turbine being installed at NREL's National Wind Technology Center (NWTC) (Photo by Dennis Schroeder)

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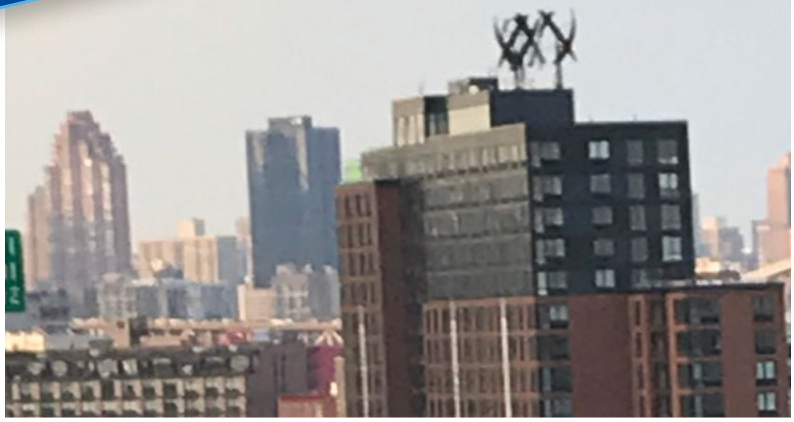
TASK 27
SMALL WIND TURBINES IN HIGH TURBULENCE SITES



Task 27 Contact and Information

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INTRODUCTION

Starting in 2009, IEA Wind TCP Task 27 held back-to-back meetings with IEC Maintenance Team 2, a group of experts who crafted the third revision of IEC 61400-2. Early on, it was determined that the standard did not address typical turbulence intensity (TI) requirements found at typical small wind turbine sites.

Further, there were no vertical velocity requirements due to lack of research and measurements. Task 27 experts suspected that turbulence would impact both wind turbine production estimates and design of appropriate standard requirements.

The objectives of the IEA Wind TCP Task 27 is to provide technical recommendations for consideration in the future revision of IEC 61400-2 based on modeling, measurements, and analysis results, and craft a Recommended Practice that offers practical guidance on micro-siting small wind turbines and rough production estimation approaches.

PROGRESS & ACHIEVEMENTS

Four meetings were held in 2017: virtual meetings in February and July and face-to-face meetings in April and October. Experts from Austria, China and Taiwan, Denmark, Ireland, Spain, and the United States attended the first virtual meeting. The second virtual meeting was attended by experts from Austria, China, Ireland, Spain, and the United States.

The spring face-to-face meeting in Dublin, Ireland was hosted by the Sustainable Energy Authority of Ireland (SEAI) in April (Figure 1). This meeting was attended by experts from Austria, China, Ireland, Japan, South Korea, Spain, and the United States.

The fall face-to-face meeting was held in Vienna, Austria, hosted by the University of Applied Sciences Technikum Wien (Figure 2). This meeting was attended by experts from Austria, Belgium, China, Ireland, Italy, Japan, South Korea, Spain, Switzerland, and the United States.

Other highlights and outreach activities included:
- SEAI Energy Show. 5–7 April 2017, Dublin, Ireland
- TurbWind 2017 Colloquium (R&I on wind energy; exploitation in urban environment) 15–16 June 2017, Riba del Garda, Italy
- 3rd Internationale Kleinwindtagung, 4–5 October 2017, Wien, Austria

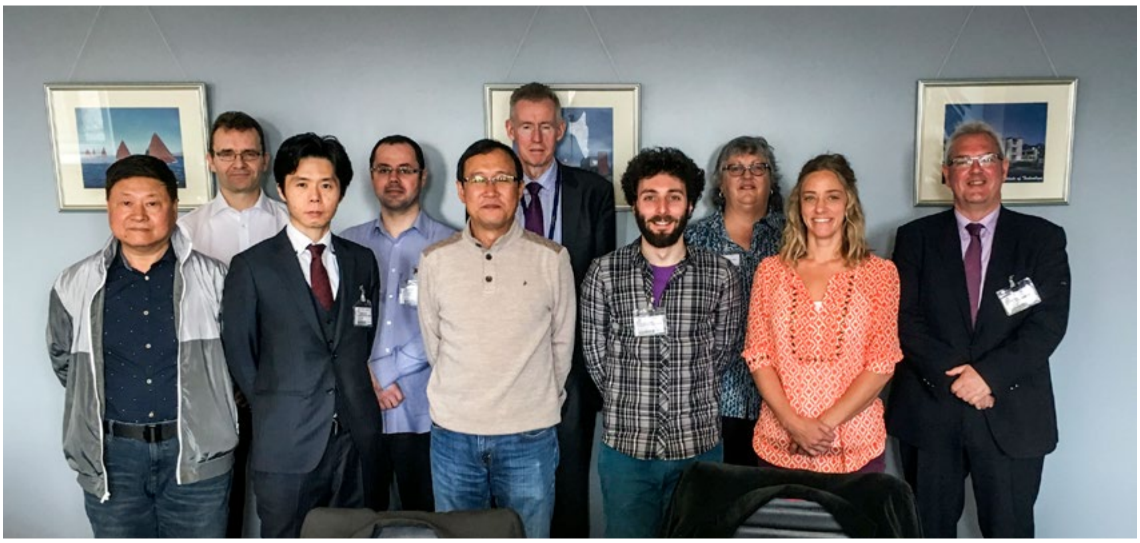

Figure 1. Task 27 meeting attendees at the Dublin, Ireland, in April 2017 (Photo credit: Ignacio Cruz)

OUTCOMES & SIGNIFICANCE

Task 27 is working to develop reasonable criteria for design requirements: vertical velocity, turbulence intensity design levels, replacement of the Normal Turbulence Model (NTM), vibration, and VAWT simplified loads methods.

NEXT STEPS

In 2018, Task 27 plans to do the following:

- Compile country case studies documenting all the CFD modeling, measurements results, and modeling and testing efforts conducted within scope of Task 27
- Compile, discuss, and complete the documentation of technical recommendations for the future IEC 61400-2 standard, fourth revision
- Finalize the IEA Wind TCP Recommended Practices on micro-siting of small wind turbines

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

Task 27 is developing practical guidelines for micro-siting small wind turbines and estimating energy production.

Understanding the Impacts of Turbulence on Small Wind Turbines

Turbulence in the turbine inflow has a significant influence on turbine production (or power performance efficiency) and the turbine lifetime. Small wind turbines operate near the ground in a vertically structured, turbulent environment. Current practice identified in the IEC standards is based on mean horizontal wind speed, but evidence exists that vertical winds may be more impactful to turbine production and loads.

The Richardson number is used to describe vertical stability and the formation of turbulence, and has been used as a requirement to capture dynamic, impulsive loads borne by turbines [1]. Task 27 experts have started to understand the vertical velocity vector and thermal stability as indicated by the Richardson number. Including these parameters in load calculations is believed to improve prediction of wind inflow beyond what is currently within the IEC 61400-2.

Neil Kelley has given a one-day workshop in Vienna on turbulence, atmospheric stability, and developed measurement methods for calculating the Richardson number and vertical velocity based on either 2-D or 3-D measurements, which are being used to compare test results. Understanding the flow stability becomes critical in identifying when fatigue damage may occur, which is found to be in weakly stable flow.

Table 1. Task 27 Participants in 2017

Member/Sponsor	Participating Organizations
Austria	University of Applied Science–Vienna
CWEA	Chinese Wind Energy Association; Inner Mongolia University of Technology; Taiwan Small & Medium Wind Turbine Association
Ireland	Dundalk Institute of Technology
Japan	Kanazawa University
Korea	Korea Institute of Energy Technology Evaluation & Planning (KETEP)
Spain	Centro de Investigaciones Energeticas Medioambientales y Tecnologicas
United States	National Renewable Energy Laboratory (NREL)
Belgium (observer)	University of Brussels
Italy (observer)	University of Trento

Figure 2. Task 27 participants at the University of Applied Sciences Technikum Wien, Vienna, in September 2016 (Photo credit: Ignacio Cruz)

References

Opening photo: UGE wind turbines at Pearson Apartment Building in Queens, New York, United States (Photo credit: Trudy Forsyth, WAT)

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

TASK 28
SOCIAL ACCEPTANCE OF WIND ENERGY PROJECTS

Task Contact and Information

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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. Due to research among industry practitioners and academics undertaken by Task 28, social acceptance of off-shore projects is now a prominent research focus.

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, Finland, Germany, Ireland, Japan, Switzerland, Portugal and the United States. Task 28 membership increased from five to eight participant countries with the welcome additions of Denmark, Finland and Portugal.

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].

PROGRESS & 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

Table 1. Task 28 Participants in 2017

Member/Sponsor	Participating Organizations
Denmark	Danish Energy Agency; Technical University of Denmark (DTU)
Finland	Akordi / Business Finland
Germany	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety; Martin Luther University; University of the Saarland
Ireland	Sustainable Energy Agency Ireland (SEAI); Queen's University Belfast
Japan	National Institute of Advanced Industrial Science and Technology; Nagoya University
Portugal	Cis-IUL, University Institute of Lisbon
Switzerland	Federal Department of the Environment, Transport, Energy and Communications; Swiss Federal Office of Energy (SFOE); ENCO Energie-Consulting AG
United States	U.S. Department of Energy (DOE); National Renewable Energy Laboratory (NREL); National Wind Technology Center; Lawrence Berkeley National Laboratory (LBNL)

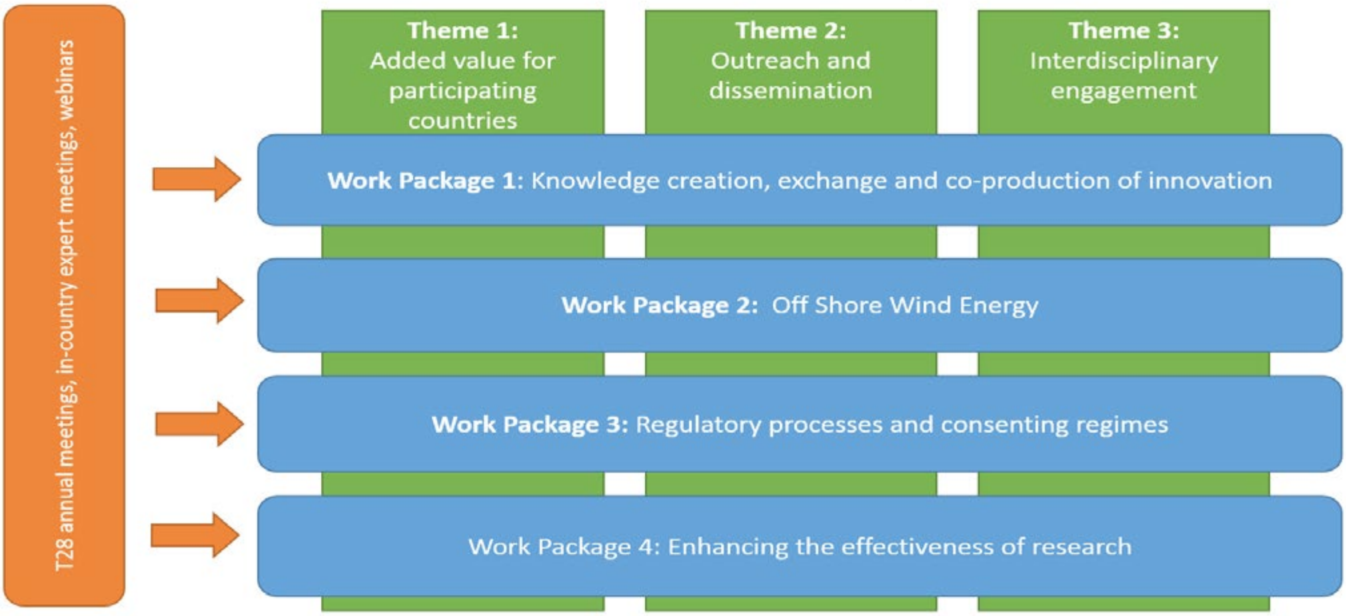

Figure 1. Priorities, themes, and work packages developed for phase three of Task 28.

OUTCOMES & 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.

NEXT STEPS

The first meeting of Phase III took place in Dublin at the end of March 2017. The meeting was preceded by a seminar, which 100 industry representatives attended. Denmark will host the next Task 28 meeting in Roskilde March 2018.

Priority TopicsTask 28 Phase III (2017-2019)

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

- Knowledge creation, exchange and co-production of innovation in social acceptance
- Offshore wind energy: unique challenges of social acceptance
- Using regulatory processes and consenting regimes to promote social acceptance
- 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.

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TASK 29

ANALYSIS OF WIND TUNNEL MEASUREMENTS AND IMPROVEMENT OF AERODYNAMIC MODELS

Task 29 Contact and Information

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INTRODUCTION

Modeling wind turbine response (i.e., power, loads, and stability) is subject to large uncertainties. Most of these come from aerodynamic modeling, due to the turbines' large size and exposure to complex aerodynamic phenomena at stalled or yawed conditions. Deficiencies in models used for turbine design can have impacts on cost and turbine reliability.

The IEA Wind TCP Task 29 Mexnext improves aerodynamic modeling for turbine design by reducing uncertainties. Phase three ran from January 2015 to December 2017, and was largely based on the New Mexico experiment.

The New Mexico experiment, a follow up to the December 2006 Mexico experiment, took place in July 2014, when researchers took measurements in the Large Low Speed Facility of the German Dutch Wind Tunnel DNW, as well as other public field and wind tunnel measurements.

PROGRESS & ACHIEVEMENTS

The New Mexico measurement database was provided to Task participants and several rounds of comparison undertaken by participants for both aligned and yawed conditions. In 2017, the participants' calculated and measured data had a greater agreement and momentum balance between loads and velocities than observed in the earlier phases of Mexnext [1].

Figure 1 shows comparisons between calculated and measured normal force as a function of radial position for design conditions (a design tunnel speed of 15 m/s, tip speed ratio of 6.66 and no yaw). The mean value of each model group is plotted with the shaded area as standard deviation.

The best agreement was found with the highest fidelity CFD calculation. Two CFD calculations were examined: one fully turbulent (CFD_turb) and one including the boundary layer transition (CFD_trans). The New Mexico blade has a tripped inner part but an untreated outer part, which explains the better agreement from the CFD-trans model.

High fidelity models produce the best results at non-design conditions, but they have the greatest computational effort. Free vortex wake models (FVW), an intermediate between CFD and BEM, predict induction-dominated phenomena (like dynamic inflow) as well as or better than CFD.

Task 29 also gained insights on phenomena like the IEC aerodynamics of pitch fault, dynamic inflow, yaw, tip effects, boundary layer transition, acoustics, and flow devices such as Guerney flaps and spoilers.

Participants assessed how physical flow field data can be extracted from lifting line variables in measurements and CFD, instead of the hypothetical lifting line variables in engineering methods. Still several challenges remain; all model results at the 60% span station gave an overprediction, which could not be explained (Figure 1).

Table 1. Task 29 Participants in 2017

Member/Sponsor	Participating Organizations
CWEA	Chinese Wind Energy Association (CWEA)
Denmark	Technical University of Denmark (DTU)
France	EDF ONERA; IFP Energies Nouvelles
Germany	Fraunhofer IWES; University of Stuttgart (IAG); Kiel University of Applied Sciences; ForWind; Windnovation; German Aerospace Laboratory DLR; Enercon; University of Kassel
Netherlands	Energy Research Center of the Netherlands; Delft University of Technology; Suzlon Blade Technology (SBT); University of Twente; Det Norske Veritas-Germanischer Loyd (DNV-GL)
Norway	Institute for Energy Technology, Norwegian University of Science and Technology
Spain	National Renewable Energy Centre of Spain
Sweden	Uppsala University Campus Gotland
United States	National Renewable Energy Laboratory (NREL)

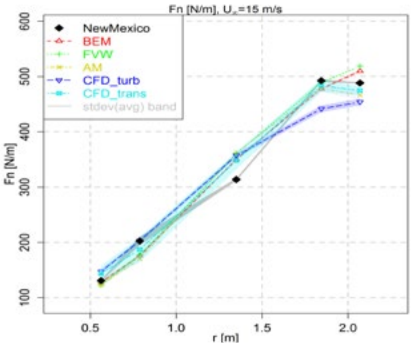

Figure 1. Comparison of calculated and measured normal forces as function of radial position at design conditions; calculations grouped per model category

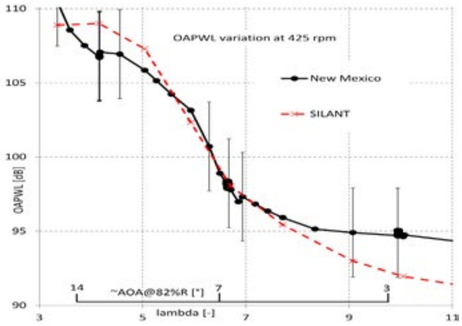

Figure 2a. Comparison between measured and calculated Sound Power Level as a function of tip speed ratio showing good agreement around design conditions

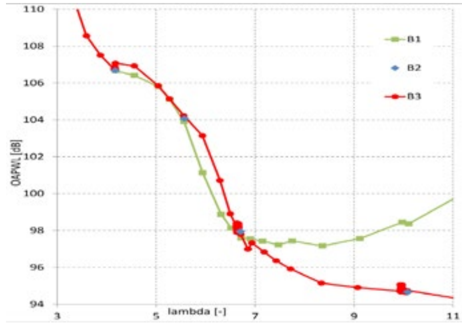

Figure 2b. Influence of the two different Guerney flap configurations (B1, B2) compared to the reference blade (B3)

OUTCOMES & SIGNIFICANCE

Uncertainties in design calculations are compensated by costly safety margins to avoid instability or failure during higher-than-expected wind turbine loads. If loads are lower than predicted, turbines can be built over-dimensioned, resulting in more costly design. Task 29 aims to reduce these uncertainties.

Task participants released numerous publications and improved aerodynamic models in 2017 and early 2018, including the Mexnext-III final report [2-17]. Task 29 also made a selection of the New Mexico data available to institutes and companies outside the consortium to improve and validate their approach to simulate rotor aerodynamics.

NEXT STEPS

At the final meeting of this current phase, the project group concluded that the Task's efforts led to a greater understanding of the blade and wake aerodynamics of the Mexico rotor. IEA Wind TCP Task 29 will continue in a new term, focusing on the DanAero field measurements.

New Mexico Experimental Data Supports Acoustics of Wind Turbines

The New Mexico experiment included both aerodynamic and acoustic measurements and the results were presented in *Wind turbine noise measurements in controlled conditions* [4, 5]. One outcome of this analysis was the comparison of the acoustic measurements with results from the Silant code, based on the Brooks Pope and Marcolini model [18]. This comparison revealed a good agreement between measured and calculated sound power level (Figure 2a).

Figure 2b shows the comparisons of the noise generated by blades with and without Guerney flaps, which are meant to increase the power production. Gurney flap configuration B1 extends to 60% of the blade and B2 extends to 40% and both flaps were found to increase the power production. However, B1 resulted in a significant noise increase, indicating that proper design of Guerney flaps is necessary to prevent increased noise levels.

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Opening photo: New Mexico experiment smoke visualizations in Large Low-Speed German-Dutch Wind Tunnel (DNW) (Photo credit: T.Westra)

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TASK 30

OFFSHORE CODE COMPARISON COLLABORATION, CONTINUED, WITH CORRELATION (OC5)

Task 30 Contact and Information

Phase: 2014-2018; 2019-2022

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INTRODUCTION

Offshore wind turbines are designed and analyzed using comprehensive simulation tools (or codes) that account for the coupled dynamics of 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.

The IEA Wind TCP previously worked to verify the accuracy of offshore wind turbine modeling tools through code-to-code comparisons with the OC3 and OC4 projects (Offshore Code Comparison Collaboration and Offshore Code Comparison Collaboration, Continued). These projects revealed how different modeling approaches influenced the simulated response of offshore wind systems. However, code-to-code comparisons can only identify differences. They do not determine the most accurate solution.

To address this limitation, OC5 (Offshore Code Comparison Collaboration Continued, with Correlation) was initiated to validate offshore wind modeling tools by comparing 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 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

PROGRESS & ACHIEVEMENTS

Phase II of OC5 was completed in early 2017. Findings were presented at the DeepWind conference in January and published in a journal article later in the year [1]. In Phase II, Task 30 validated numerical models of the 1/50th-scale DeepCwind floating semisubmersible wind system using measurement data from the MARIN offshore wave basin.

These results showed that, although state-of-the-art tools captured some of the dynamics and loads of this complex floating wind turbine, there were persistent differences between the simulated results and measurements, the reasons for which could not be ascertained. For example, ultimate and fatigue loads were under-predicted across multiple load cases, especially at the pitch and tower natural frequencies.

To answer these outstanding questions, a sub-group within OC5 performed further testing of the semisubmersible at the MARIN wave basin. Testing was performed under the EU-funded MaRINET2 project, which provides free testing time at offshore wave basins and other facilities for renewable energy devices (obtained through a competitive solicitation). The validation campaign assessed the confidence in the hydrodynamic response of the semisubmersible at low frequencies through the reduction and assessment of uncertainty in the experimental tests. Uncertainty reduction was achieved by simplifying the mooring system from its original catenary configuration and by removing the wind turbine. The data is expected to be examined within OC6.

Phase III of the project, started in 2017, verifies and validates models using data from the full-scale, open-ocean alpha ventus wind farm—the first German offshore wind farm. The validation work employs a REpower 5M (currently Senvion) wind turbine placed atop an OWEC Tower jacket support structure. Initially, this phase developed and verified the wind turbine model for this system. Due to intellectual property rights, the full model properties, including the controller, were not provided. However, the University of Stuttgart had access to the full turbine properties, which allowed the Task to tune the models within the OC5 project to their model.

Verification work was completed by comparing individual models of the wind turbine and tower to the reference model developed by the University of Stuttgart for a variety of load cases. Complexity was built up by first comparing mass and static forces, then the eigen properties, loads for a rigid turbine during power production, and finally loads for a flexible turbine during power production.

The verification results will be published at the ASME 2018 37th International Conference on Ocean, Offshore and Arctic Engineering OMAE 2018 in Spain in June 2018 [2].

Figure 1 shows a sample of the results from this work, displaying the frequency response behavior and distribution of the loads at the base of the tower under turbulent wind. The results show a good comparison between the models, with a few outliers that need further examination. Based on these results, the group is now ready to begin validating the tuned models to measurements from the alpha ventus jacket.

Since the start of the OC5 project, 188 participants from 77 organizations in 19 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.

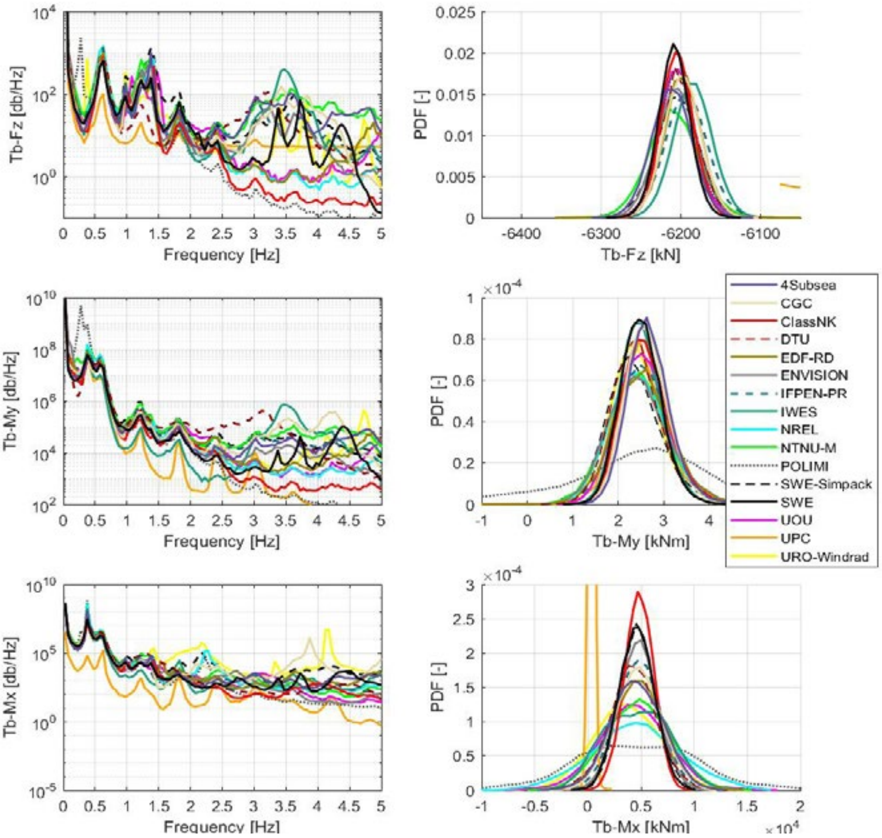

Figure 1. Power spectral and probability density functions of the tower-base shear forces and moments for operational conditions with a turbulent wind field for the alpha ventus jacket.

OUTCOMES & 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. Improving engineering tools and methods will enable offshore wind industry to develop more optimized designs.

NEXT STEPS

The OC5 project was extended due to issues with intellectual property rights for the commercial system data, and a no-cost extension of the project was approved through the end of 2018. Validation of the alpha ventus jacket will be completed in 2018 and will conclude the OC5 project.

An extension, OC6, will start in January 2019, and will focus on better understanding the nonlinear hydrodynamic loading for offshore wind systems, aerodynamic modeling capabilities under large motion, and soil/structure modeling capabilities. Higher-fidelity models to inform the validation process and a stronger focus on identifying and quantifying uncertainty in the test campaigns will be incorporated in the project.

Table 1. Task 30 Participants in 2017

Member/Sponsor	Participating Organizations
CWEA	China General Certification Center; Envision; Dalian Univ. of Technology; Goldwind
Denmark	DTU Wind Energy; Danish Hydraulic Institute
France	PRINCIPIA; EDF; IFP Energies nouvelles
Germany	Univ. of Rostock; Siemens Gamesa Renewable Energy; Fraunhofer IWES; Univ. of Stuttgart SWE
Italy	Polytechnico Di Milano
Japan	Univ. of Tokyo; Wind Energy Institute of Tokyo Inc.; ClassNK
Korea	University of Ulsan
Netherlands	The Knowledge Centre WMC; MARIN
Norway	Norwegian Univ. of Science and Technology; Institute for Energy Technology; 4Subsea; Simis; SINTEF Ocean
Portugal	Wave Energy Centre; CENTEC
Spain	Siemens PLM; Univ. of Cantabria; Tecnalia; Polytechnic Univ. of Catalonia; National Renewable Energy Centre of Spain
United Kingdom	DNV GL; Wood Group; Lloyd's Register; Cranfield Univ.
United States	National Renewable Energy Laboratory; University of Maine; University of Massachusetts; Texas A&M University

References

Opening figure: Open ocean offshore wind system design examined in Phase III of OC5 (Photo credit: Gary Norton, NREL, 27360)

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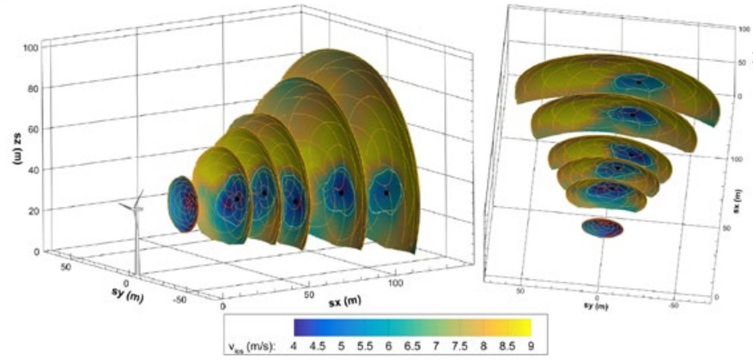
Authors: Amy Robertson, NREL, United States; and Wojciech Popko, Fraunhofer IWES, Germany.

TASK 31

WAKEBENCH: BENCHMARKING WIND FARM FLOW MODELS



Task 31 Contact and Information

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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, giving 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 between them. The next generation of wind-energy models need 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 (V&V) framework that will support a sustained improvement of wind farm models. The task will employ a continuous evaluation process, simulating as many test cases as possible to gain confidence and credibility from the results as they apply to the intended use of the model and its range of applicability [3, 4].

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 the U.S. Department of Energy's Atmosphere to Electrons (A2e) program. Both share common objectives (multiscale modeling, experimental campaigns, V&V, open access to data) and will use Task 31 to reach out to the international community.

PROGRESS & ACHIEVEMENTS

Task 31 phase two kicked off in 2015 and includes 10 participating countries: China, Denmark, Finland, France, Germany, Japan, the Netherlands, Spain, Switzerland, Sweden, and the United States.

The NEWA project supported activities related to the development of flow models for external wind conditions. The GABLS3 benchmark tested meso-micro coupling methodologies for the simulation of a diurnal cycle at the Cabauw meteorological mast in the Netherlands [5]. More than ten participants took part in this benchmark, using meso- and microscale models as well as different ways of interfacing.

This led to the "NEWA Meso-Micro Challenge for Wind Resource Assessment," which aims to determine the applicability range of meso-micro methodologies across the validation envelope of NEWA experimental sites such as Hornamossen forested rolling hills in Sweden, Rödeser Berg isolated forested hill in Germany, Perdigão double-hill in Portugal, and Alaiz mountain range in Spain. The validation strategy is based on flow cases targeting specific modeling objectives and wind-climate integrations to assess the wind resource and site suitability (annual energy production, turbulence intensity, wind shear, etc.).

In A2e, Sandia NL and NREL conducted an experiment at the Scaled Wind Farm Technology (SWiFT) to characterize wake steering effects from a yawed turbine [6]. Additionally, the Offshore Wind Accelerator (OWA) Rodsand 2 scanning lidar experiment is being analyzed to study array effects in large wind farms in the open sea, coastal effects, and farm-to-farm effects from the Nysted wind farm. Most data from these experiments will be available through 2018 and exploited throughout the Task 31 phase three.

Task 31 is developing a verification and validation (V&V) framework to support sustained improvement of wind-farm models.

OUTCOMES & 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 V&V integrated planning for wind farm performance by prioritizing experiments and simulations that can have the greatest impact on improving design tools.

Through benchmarking, researchers leverage data and share results from existing projects for wider exploitation in an international context. Industry can also 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.

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, considering 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 [7].

Table 1. Task 31 Participants in 2017

Member/Sponsor	Participating Organizations
CWEA	North China Electric Power Univ.; Huaneng Clean Energy Research Institute; Goldwind; Envision
Denmark	DTU; DONG Energy; VESTAS Wind and Site Competence Centre; EMD International A/S
France	EDF R&D; IFP Energies Nouvelles; Universite du Havre; Meteodyn; Universite d'Orleans
Germany	ForWind Oldenburg University; DEWI; SUZLON; German Aerospace Center
Japan	University of Tokyo; Wind Energy Institute of Tokyo; New Energy and Industrial Technology Development Organization
Netherlands	Energy Research Centre of the Netherlands; Technical Univ. of Delft
Spain	National Renewable Energy Centre of Spain; EDP Renovaveis
Sweden	Upsala University
Switzerland	Ecole Polytechnique Federale de Lausanne; Swiss Federal Institute of Technology
United States	National Renewable Energy Laboratory (NREL); Sandia National Laboratories; Cornell University.; Univ. of Wyoming; National Center for Atmospheric Research; Lawrence Livermore National Laboratory; Univ. of Texas at Dallas; Univ. of Colorado Boulder

Figure 1. The DOE/Sandia Scaled Wind Farm Technology (SWiFT) facility at the Reese Technology Center (Lubbock, Texas) allows for rapid, cost-efficient testing and transformative wind energy technology development, with an emphasis on improving wind plant performance. The facility's advanced testing and monitoring helps researchers evaluate how larger wind farms can be more productive. (Photo credit: Sandia National Laboratories/Lloyd Wilson)

Outlook for Task 31 Phase 3 (2018-2021)

The next phase of Task 31 will focus on adopting an international validation strategy for wind resource assessment, site suitability, and numerical site calibration applications. This phase will be achieved by rolling out the validation plans established in the NEWA and A2e research initiatives, which will be aligned with the end-user requirements from IEC 61400-15 and IEC 61400-12-4 working groups. Further efforts will be conducted to implement open-science practices in the model evaluation protocol to improve traceability and interoperability of the validation repositories produced.

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Opening Figure: Example of lidar measurements from the SWiFT steering-wakes experiment (Source: Sandia National Laboratories)

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Author: Javier Sanz Rodrigo, CENER, Spain.

TASK 32

LIDAR: WIND LIDAR SYSTEMS FOR WIND ENERGY DEPLOYMENT

Task 32 Contact and Information

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INTRODUCTION

Lidar technology provides a remote sensing alternative to traditional wind measurement techniques. The IEA Wind TCP Task 32 identifies and mitigates barriers to using lidar for the following applications: site assessment, power performance, loads and control, and complex flow. In 2017, participants added new application area "out-of-the-box" to incorporate new topics and account for changing needs in the lidar community.

Task 32 addresses these application areas individually through workshops, as 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 ideas, experiences, and measurement techniques for using lidar in wind energy.

Task 32 continues to strengthen the international exchange of knowledge, experience, and ideas that foster the lidar use in wind energy. In total, 219 persons from 106 institutions and 18 countries (12 member countries and six interested countries) participated in Task 32 from the start of Phase two in 2016 through the end of 2017. Participating institutions include research centers, universities, wind measurement companies, and lidar and wind turbine manufacturers.

PROGRESS & ACHIEVEMENTS

In 2017, three workshops were organized:

Workshop #5 on Elaboration of Use Cases in Wake and Complex Flow Measurements: Challenges that arise in complex flow require adopting sophisticated methods that can accommodate the observed phenomena. Task 32 met this challenge by developing the Lidar Use Case, which captures and documents critical information, i.e., data requirements and measurement method and situation, so diverse lidar methods can be applied in a user-neutral, repeatable manner. This workshop explored a variety of wind turbine wake cases.

Workshop #6 on Power Performance Measurement Using Nacelle Lidars: Nacelle lidars promise alternatives to mast-mounted cup anemometers for wind turbine power performance verification. The technology has been tested and adopted for internal use by many industry stakeholders over the last five years, including turbine manufacturers, wind farm developers, and certification bodies. At this stage, common understandings and standardized techniques are needed.

The workshop addressed the calibration of nacelle lidars and related uncertainties, and wind turbine power curve measurements using nacelle lidars. Workshop outcomes were presented at the kick-off meeting for the group tasked with writing the new IEC standards regarding nacelle mounted lidars for wind measurements (PT61400-50-3).

Workshop #7 on Lidar Campaigns in Complex Terrain: After opening presentations, attendees identified challenges to using lidar in complex terrain. In industry applications the strongest need was for best practices and standards, while research-oriented applications were challenged by personnel and equipment costs. A common challenge was the level of expertise required, which could be offset by embedding best practices in support software. These challenges are being addressed by the wind lidar community.

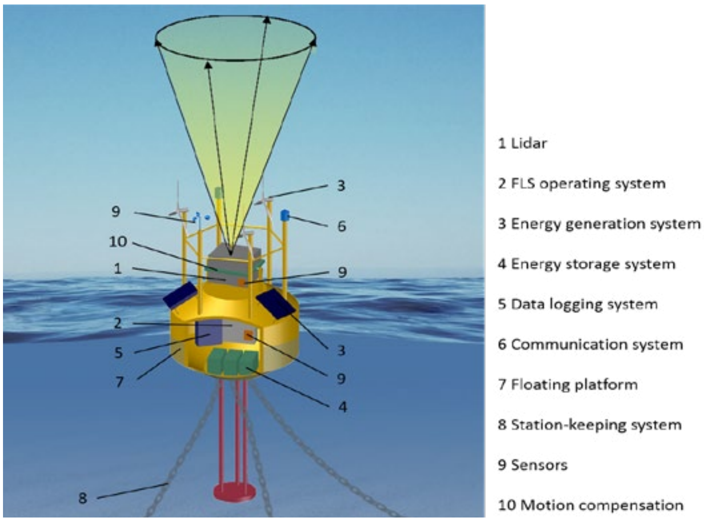

Figure 1. Diagram of a floating lidar system.

Table 1. Task 32 Participants in 2017

Member/Sponsor	Participating Organizations
Austria	Energiewerkstatt
Canada	AXYS; TechnoCentre Éolien
CWEA	Envision; Goldwind; Huaneng Clean Energy Research Institute; MingYang
Denmark	COWI; EMD International; Ørsted (previously DONG Energy); Siemens; Suzlon; Technical University of Denmark (DTU); Windar Photonics; Wind Solutions
France	Epsiline; EOLFI; IFP Energie nouvelles; Leosphere; University of Orleans
Germany	Deutsche WindGuard; DEWI; DLR; DNV GL; Enercon; E.ON; Fraunhofer IWES; GE Global Research; GWU-Umwelttechnik; HAW Hamburg; KIT Institute of Meteorology; M.O.E. GmbH; Multiversum; OpticSense Senvion; sowento; University of Stuttgart SWE; University of Oldenburg; Wind-consult; WindForS; Windtest Grevenbroich; ZSW
Japan	Advanced Industrial Science and Technology; Mitsubishi Electric Corporation; Wind Energy Institute of Tokyo
Korea	Jeju Energy Corporation; Jeju National University; Korea Testing Laboratory; Korean Register
Netherlands	Energy Research Centre of the Netherlands (ECN); Netherlands Enterprise Agency; Solidwinds; TU Delft; Vattenfall
Norway	Christian Michelsen Research; Fugro
United Kingdom	Babcock International Group; Carbon Trust; DNV GL; EDF Energy; Fraunhofer Centre for Applied Photonics; Frazer Nash; Mott MacDonald; Natural Power; NEL; Nordex; Offshore Renewable Energy Catapult (ORE); Ørsted (previously DONG Energy); RES; SgurrEnergy; SSE; Texo Drone Survey and Inspection; Univ. of Glasgow; Univ. of Strathclyde; Wind Farm Analytics; ZephIR Lidar
United States	AWS Truepower; Business Network for Offshore Wind; Colorado School of Mines; Cornell University; DNV GL; DOE; Envision Energy; E.ON; GE; Mitsubishi Electric Research Laboratories; NREL; Pacific Northwest National Laboratory (PNNL); Renewable NRG Systems; Sandia, Siemens; Univ. of Colorado Boulder; Univ. of Maryland; Univ. of Wyoming; V-Bar

OUTCOMES & SIGNIFICANCE

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 measurement projects on the performance of lidar devices and associated measurement techniques.

In 2017, 12 Advisory Board meetings and a General Meeting were held as well as the three workshops described on the previous page. The meeting minutes, workshop proceedings, and reports can be found at www.ieawindtask32.org.

Additionally, two newsletters were distributed to around 400 interested experts and the IEA Wind TCP *RP 18: Floating Lidar Systems* was published.

NEXT STEPS

At least five workshops will be organized in 2018 based on the General Meeting outcomes and follow-up Advisory Board meetings. The following workshop topics are being considered:

- Certification of lidar-assisted control applications
- Very short-term forecasting with lidar in collaboration with IEA Wind TCP Task 36 (Forecasting)
- Wind field reconstruction in the induction zone using nacelle lidars
- Load verification with nacelle-based lidar
- Complex terrain definition and impact on wind field reconstruction

IEA Wind Task 32 will continue to provide a forum for the exchange of knowledge and experience relating to wind lidar. The increasing interest in the Task events shows the high relevance and the need for continuation; therefore, a task extension will be prepared.

RP 18 - Floating Lidar Systems: Guidance for floating lidar systems in wind resource assessments

Floating lidar systems have emerged as wind-resource assessment tools for offshore wind farms, with the potential to reduce installation costs more than fixed meteorological masts. To be considered effective wind measurement options, these systems must overcome two main challenges:

- Sea movement imparting motion on the lidar, which creates challenges to maintaining wind speed and direction accuracy
- The remoteness of the deployed system, which necessitates robust, autonomous, and reliable operation of measurement, power supply, data logging, and communication systems.

There is no standard for deploying these systems to get the best quality data for a wind resource assessment. Therefore, a Recommended Practice (RP) document was required to guide the use of floating lidar systems in wind resource assessments.

Task 32 published *RP 18: Floating Lidar Systems* in 2017. This document codifies existing industry and academic best practices to ensure that the best quality floating lidar system data are available in the wind energy resource assessment process.

References

Opening photo: Scanning lidar system at the Perdigão Experiment for the New European Wind Atlas project (Photo credit: Robert Menke, DTU, Department of Wind Energy)

Authors: David Schlipf and Ines Würth, SWE, University of Stuttgart, Germany; Andrew Clifton, WindForS, University of Stuttgart, Germany; and Julia Gottschall, Fraunhofer IWES, Germany.

TASK 34

WORKING TOGETHER TO RESOLVE ENVIRONMENTAL EFFECTS OF WIND ENERGY (WREN)

Task 34 Contact and Information

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WREN Hub: tethys.pnnl.gov/about-wren

INTRODUCTION

Questions about the impact of wind energy on wildlife can result in project development challenges. 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.

WREN leverages the resources and expertise of member and nonmember countries and their extended networks to expand this knowledge base (Table 1). 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.

PROGRESS & ACHIEVEMENTS

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

Table 1. Task 34 Participants in 2017

Member/Sponsor	Participating Organizations
Canada	Environment and Climate Change Canada
France	EDF Energies
Ireland	BirdWatch Ireland
Netherlands	Rijkswaterstaat, Department of Water Quality
Norway	Norwegian Institute for Nature Research
Portugal	STRIX; Bio3
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; Pacific Northwest National Laboratory; U.S. Department of Energy

In addition to providing access to relevant literature and products developed within the Task, WREN Hub provides information on key contacts, archives of webinars and online meetings, upcoming events, and other social media outreach forums as deemed appropriate. WREN Hub is part of the Tethys website (Figure 1). Updates to WREN Hub in 2017 include:

- Adding 186 wind-energy-relevant documents to the database
- Improving content tagging and filtering
- Adding calendar downloads to WREN events
- Completing the Tethys peer review

WREN members participated in the Conference of Wind energy and Wildlife impacts (CWW), held in Portugal in September 2017 (see Boxed Highlight for details). In conjunction with CWW, WREN convened a workshop to reach out to the larger international community, seeking input for the three remaining white paper topics, described below.

Three webinars were held in 2017, all of which were recorded and posted on WREN Hub (Table 2). Progress was made on three white papers: environmental risk-based management; cumulative impacts of wind energy on wildlife; and "green

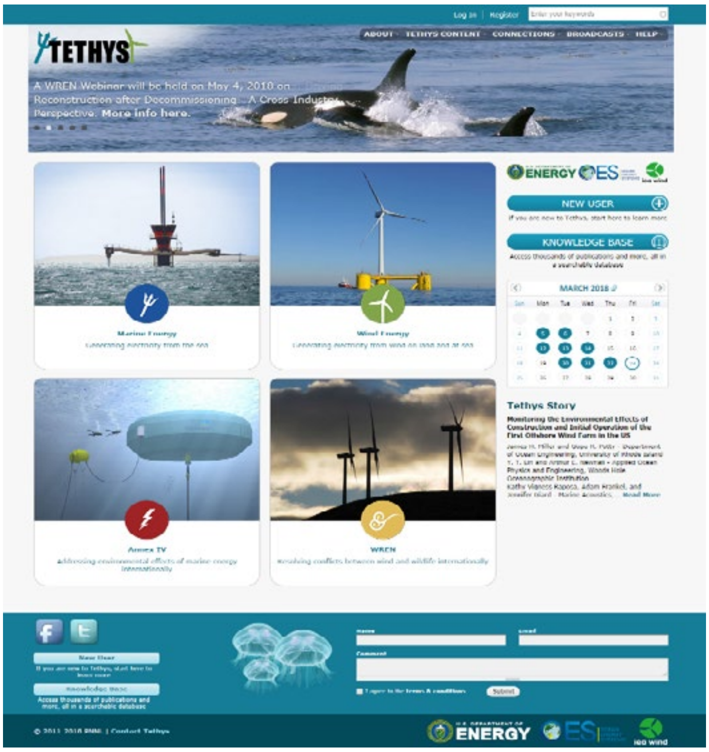

Figure 1. The Tethys website provides direct access to WREN Hub (Source: https://tethys.pnnl.gov/)

Disseminating research results to the wider international wind community

WREN members participated in the 2017 Conference of Wind energy and Wildlife impacts (CWW) in Estoril, Portugal. The CWW brought together 300 participants from 20 countries. Numerous WREN member countries presented research results on reducing impacts to wildlife at land-based and offshore wind facilities. A poster on WREN was also presented.

WREN also sponsored a workshop, “Strategies and Concepts for Managing Wind and Wildlife Challenges,” in conjunction with the CWW. The workshop gathered global expertise and experience to understand how risk-based management, cumulative effects analysis, and green versus green can be applied to improve the management of, and decrease conflicts between, wind and wildlife interactions. Twenty-one participants from ten countries joined 12 WREN members to discuss these concepts and provide input to in-progress white papers.

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. For example, the representative from the Netherlands regularly shared WREN information with a mailing list of 50 contacts that includes government staff, consultancies, nongovernmental organizations, and wind companies, while the Irish WREN representative communicated WREN achievements and events to a list of 160 contacts in Ireland.

In addition to communicating with their countrymen, the Portuguese representatives hosted the CWW in September 2017, which featured WREN papers. The Swiss WREN representative delivered several presentations on WREN papers to interested wind developers, government officials, and planning bodies in Switzerland.

Table 2. WREN Webinar Participation & Downloads

Webinar Topic	Date	Attendees/ Page Views
BOEM Efforts to Collect and Analyze Offshore Wind Data in a Holistic Manner, as Demonstrated through the RODEO Study	28 March 2017	42/416
Research Programs to Understand the Environmental Impacts of Offshore Wind, Part 2	20 June 2017	60/291
Upscaling Wind and Wildlife Individual Interactions to Population-Level Impacts	20 Sept. 2017	70/494

OUTCOMES & SIGNIFICANCE

To meet policy objectives and decrease reliance on carbon-based energy sources, countries must address concerns regarding the negative impacts from wind energy. Task 34 activities result in more informed decision making, as WREN provides access to an expanded knowledge base and connections to others involved in wind-wildlife topics, such as:

- Research on species and/or habitat issues
- Development and testing of mitigation strategies and technology solutions
- Development and implementation of regulations and guidelines
- Policy decisions that affect wind energy deployment

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

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. Two in-person meetings are planned for 2018; one will take place in the Netherlands in May and the other in Spain in October.

References

Opening photo: Eastern Red Bat with a radio-tag is part of research on Anthropogenic Influences on Landscape Movement and Population Viability of Ontario Bat Species. (Photo credit: Sherri and Brock Fenton)

Author: Karin Sinclair, NREL, United States.

TASK 35

FULL SIZE GROUND TESTING FOR WIND TURBINES & THEIR COMPONENTS

Task 35 Contact and Information

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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 a result, the wind turbine industry considers full-size ground testing an attractive option for validating wind turbine designs, due to faster, reproducible test campaigns and lower commissioning effort [1].

The goal of IEA Wind Task 35 was to develop recommendations for full-size ground testing procedures for rotor blades and nacelles across test facilities around the world. Depending on the configuration, test rigs should perform the same standardized test procedures with equivalent results at the same confidence level. As a long-term goal, the standardized test procedures should support the:

- Advancement of the certification process
- Improvement of the quality and reliability of nacelles and rotor blades
- Optimization of wind turbine design
- Reduction of wind turbine development time
- Evaluation of the in-field performance and possible failure modes of rotor blade and nacelle components

PROGRESS & ACHIEVEMENTS

IEA Wind TCP Task 35 was composed of two subtasks:

- Subtask Nacelle, which worked on recommendations for nacelle tests, and
- Subtask Blade, which elaborated recommendations for rotor blade testing.

Subtask Nacelle

Subtask Nacelle finished a technical report in early 2017. This technical report provided background, objectives, and conclusions for Subtask Nacelle, as well as an overview of the different test facilities around the world and their functionality and capabilities. Task 35's consortium also evaluated and analyzed the influences different abstractions had on ground-based test rigs. The report provided a methodology and unified wording for describing nacelle test procedures, which is elaborated through two elementary examples. These elaborations provide useful information about how to conduct these tests and which loads may be relevant.

Subtask Blade

As blades increase in size and scale, new validation challenges arise. To keep pace with the scale and advances in designs of wind turbine blades, developers continually improve their methods for characterizing structural performance. Existing test methods may not adequately quantify the service loads that blades could experience in field operation. To optimize blade design, it is important to evaluate significant load cases and develop methods to properly emulate these loads in the laboratory, yielding realistic and conservative results.

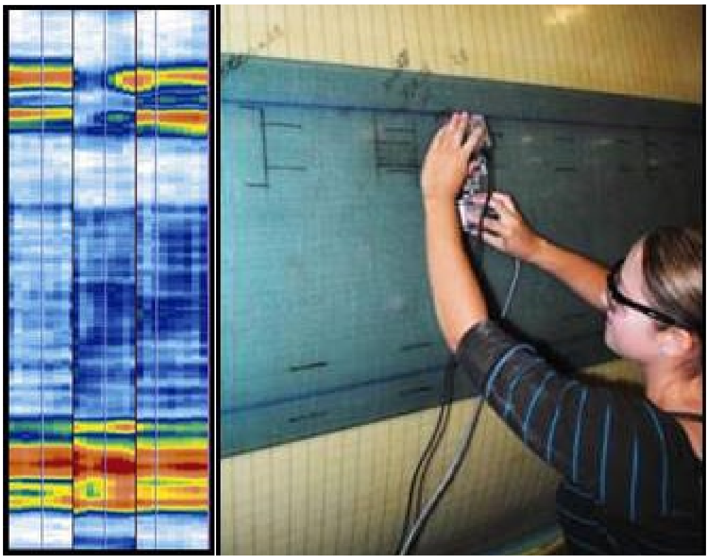

Figure 1. Nondestructive Inspection, a topic area of Subtask Blade (Source: Sandia National Laboratories)

The cost and time required to perform complete blade testing increases as blades grow. By developing and accepting subcomponent test methods, developers can attain a means to quickly evaluate the performance of large components. As turbines are deployed in increasingly extreme environments, including taller tower heights and offshore and near-shore environments, nondestructive test methods may be necessary to ensured blade reliability.

Table 1. Task 35 Participants in 2017	
Member/Sponsor	**Participating Organizations**
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); 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	Center for Wind Power Drives (CWD), RWTH Aachen University; Fraunhofer IWES; Senvion GmbH; GE Energy Power Conversion GmbH; MTS Systems GmbH; Windtest Grevenbroich GmbH; HBM- Hottinger Baldwin Messtechnik GmbH; Tüv Rheinland AG; Technical University of Berlin; Siemens AG (Winergy)
United Kingdom	Offshore Renewable Energy Catapult; 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; Sandia National Laboratories; MTS Systems Corporation
Korea (Observer)	Korea Institute of Materials Science (KIMS)
Netherlands (Observer)	Knowledge Centre Wind turbine Materials and Constructions (WMC); We4Ce B.V.
Spain (Observer)	National Renewable Energy Centre (CENER); Ingeniería y Dirección de Obras y Montaje (IDOM)

While subcomponent testing is in early stages of development, comparing current testing protocols, as well as any technical gaps will enable further improvement and standardization.

Although the goal of blade testing is well understood and codified in international standards, test methods for introducing test loads and reporting and interpreting results still vary between laboratories.

Subtask Blade identified four key areas where improvements in current practices could lead to robust validation methods. These include:

- Development of subcomponent test methods
- Comparison of test methods
- Nondestructive evaluation
- Uncertainty estimation

In each of these areas, participants contributed insight into their current testing practices. The Task developed technical approaches for calculating uncertainty for static, fatigue, and modal testing, and defined detailed examples of several suitable calculation methods. Providing detailed examples for the expression of uncertainty, which included both Type A and Type B uncertainties, should help harmonize results between test laboratories. Similarly, identifying gaps in the methods used to calculate applied test loads in the flap and edge directions will lead to a proper methodology for measuring and reporting multi-axial loading. While subcomponent testing is in early stages of development, comparing current testing protocols, as well as any technical gaps will enable further improvement.

The rotor subtask has completed technical documentation of all four topic areas, and a published report of Subtask Blade will be completed in 2018. Although Task 35 is complete, there remains useful work that future working groups could undertake, including further development of rotor subcomponent test methods and evaluation of new structural and non-structural test needs (e.g., torsion and coupled mode characterization and erosion testing).

Task 35 Collaboration: Harmonizing International Test Methods

Wind turbine rotor blade testing has developed over the past 30 years, with current practices prescribed by the IEC 61400-23 standard. Differences between blade test rigs, advances in blade design and evaluation methods, the steady pace of increasing blade scales, and practical testing experience have identified gaps in current validation methods for modern turbine blades.

Collaboration between international laboratories within Task 35 has been valuable in comparing and harmonizing test methods. By harmonizing test methods, manufacturers and operators will gain confidence in blade test results. The Task's efforts have led to a better understanding of emerging test requirements and increasingly common validation methods, including rotor blade subcomponent testing. Information and ideas resulting from Task 35 are immediately impactful, as a maintenance team begins to revise the IEC 61400-23 standard.

ACKNOWLEDGEMENTS

We would like to thank all supporters of IEA Wind TCP Task 35. The work groups helped establish a strong community of test rig operators, turbine manufacturers, and other stakeholders, which will allow an accelerated information flow between test facilities and industry worldwide. Even though Task 35 is closed, the community's efforts will still enrich the wind industry. Finally, we would especially like to thank the IEA Wind TCP Secretariat and the Executive Committee for supporting the task.

References

Opening Photo: 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," November 23, 2011. Download from: www.sa.areva.com/EN/news-9108/offshore-wind-turbines-areva-s-5-megawatt-full-load-test-bench-in-operation-since-october-2011.html

Author: Tobias Duda, Dennis Bosse, and Georg Jacobs, Center for Wind Power Drives at RWTH Aachen University; Scott Hughes, National Renewable Energy Laboratory, United States.

TASK 36
FORECASTING FOR WIND ENERGY

Task 36 Contact and Information

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INTRODUCTION

The IEA Wind TCP Task 36 improves the value of wind energy forecasts by improving meteorological wind speed forecasts and power conversion steps usually done by forecast vendors, as well as facilitating better use of the forecasts. The Task is the largest global group devoted to wind power forecasting, combining meteorologists, researchers, operational forecaster vendors, and end users, bringing together experts from all aspects of the forecasting chain to develop documentation and standards that can take power industry to the next level.

Work Package 1, led by Helmut Frank of Deutscher Wetterdienst and Will Shaw from the Pacific Northwest National Laboratory, aims to improve Numerical Weather Prediction (NWP) models.

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.

Work Package 3 disseminates research results and documentation. Led by Georges Kariniotakis of MINES ParisTech and Corinna Möhrlen of WEPROG, its objective is to help end-users in optimize forecasting processes and incorporate probabilistic forecast information into the operational processes.

PROGRESS & ACHIEVEMENTS

Work Package 1 has released a list of meteorological masts standing 100 m or taller, including location information and instructions for accessing access online data, which can be used to verify wind profiles and wind speeds [1].

Task 36 also compiled a list of meteorological field campaigns, with contributions from the Wind Forecast Improvement Project (WFIP 2) in the United States' Columbia River Gorge, as well as the New European Wind Atlas (NEWA) campaigns in Perdigao, Portugal, near Kassel, Germany, and in Alaiz, Spain. Participants also placed a lidar on a ferry traversing the Baltic Sea and conducted the near-shore RUNE experiment in Jutland, Denmark.

Work Package 2 expects to publish an IEA Wind TCP Recommended Practice (RP) in 2018 on implementing wind power forecasting solutions:

- Forecast Solution Selection Process: how to choose or renew a forecasting solution for the power system or market.
- Benchmarks and Trials: how to set up and run benchmarks and trials to evaluate different forecasting solutions against each other and the fit-for-purpose.
- Forecast Evaluation: provides information and guidelines regarding effective evaluation of forecasts.

Work Package 2 is also compiling a document on evaluation criteria, listing common and novel evaluation metrics and discussing when and how to employ them. Finally, participants published a list of freely available data sets on the Task website; these data sets are well-suited for R&D of wind power forecasting models.

Work Package 3 published two articles in 2017, based on a survey from the previous year. These articles revealed a significant gap between available products on the market and the lack of knowledge and documentation in how to apply, decide, and make efficient use of probabilistic forecasts by end-users.

Task 36 prepared ten oral presentations and a poster for the Special Session of the American Meteorology Society Annual Meeting in Seattle, United States in January 2017 and gave two days of oral presentations at the Wind Energy Science Conference in Lyngby, Denmark, in June 2017 [2, 3].

Applicability of Uncertainty Forecasts in the Electric Power Industry

A highlight of 2017 was the publication of a journal article led by Ricardo Bessa and Corinna Möhrlen [4]. Jan Dobschinski et al. later rewrote some of the main items for the *IEEE Power and Energy Magazine* [5].

Deterministic forecasts are still predominant in utility practice, although truly optimal decisions and risk hedging are only possible with uncertainty forecasts. Several barriers contribute to the mistrust of uncertainty forecasts and their applicability in practice, such as a lack of understanding regarding information content (e.g., physical and statistical modeling) and proper application, as well as a lack of standardization among uncertainty forecast products.

Task 36 aimed to establish a common terminology in the article and review the methods to determine, estimate, and communicate uncertainty in weather and wind power forecasts. This analysis of the state-of-the-art highlights that:

- End-users should look at the forecast's properties to map different uncertainty representations to specific wind energy-related user requirements
- A multidisciplinary team is required to foster the integration of stochastic methods in the industry sector.

Recommendations for standardization and improved training are provided along with examples of best practices.

Table 1. Task 36 Participants in 2017

Member/Sponsor	Participating Organizations
Austria	Zentralanstalt für Meteorologie und Geodynamik
CWEA	China Electric Power Research Institute; China Meteorological Administration; Envision; North China Electric Power Univ.; Xinjiang Goldwind; Zhejiang Windey
Denmark	Technical University of Denmark; Denmarks Meteorological Institute; DNV GL; ENFOR; WEPROG; Energinet; Vestas; Vattenfall; ConWX
Finland	VTT Technical Research Centre of Finland; FMI; Vaisala
France	MINES ParisTech; MeteoSwift; MetEolien; Electricité de France; Compagnie Nationale du Rhône; Engie Green; Réseau de transport d'électricité
Germany	Deutscher Wetterdienst; Fraunhofer IEE; ForWind; Zentrum für Sonnenenergie und Wasserstoff-Forschung; WindForS; EWC; 4cast; Stuttgart Univ.; Enercon; Tennet
Ireland	Dublin Institute of Technology; Univ. College Dublin
Norway	Meteorologisk Institutt; Christian Michelsen Research; Kjeller Vindtekknik
Portugal	INESC TEC; Prewind; Smartwatt; Laboratorio Nacional de Energia e Geologia
Spain	Vortex; Iberdrola Renovables; Electricidade do Portugal Renovaveis; Red Electrica de España
Sweden	Vattenfall
United Kingdom	MetOffice; Reading University; Strathclyde Univ.; UK National Grid
United States	PNNL; NREL; National Oceanic and Atmospheric Administration; National Center for Atmospheric Research; Electric Power Research Institute; MESO, Inc.; Univ. of North Carolina Charlotte

OUTCOMES & SIGNIFICANCE

Task participants are preparing a RP on selecting the optimum forecast solution and setting up a benchmarking process, including guidance on using error measures for typical evaluation scenarios. The document will be reviewed by commercial forecasters, stakeholders, and end users to ensure it benefits all groups.

As solar and wind forecasting employ similar methods, Task 36 plans to collaborate with the IEA PVPS Task 16 on solar forecasting. The Task is also producing publications for the scientific and engineering communities. These will serve as reference material for the recommended practices guidelines and to further study wind power forecasting.

Figure 1. Task meeting participants: Amsterdam, January 2017 (Photo Credit: Corinna Möhrlen)

NEXT STEPS

Task 36 will continue moving forward on several deliverables:

- Special session at the ESIG Forecasting Workshop in St. Paul, United States [6]
- Publish the Recommended Practice of Work Package 2.1 Forecast solution selection and benchmark and trials
- Distribute second version of tall towers overview, meteorological experiments lists, and links to existing benchmarking data sets
- Write a new work program for the second round of Task 36 for the next three years.

References

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

[1] www.ieawindforecasting.dk

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

[3] www.wesc2017.org

[4] R. Bessa, et al. (2017). "Towards Improved Understanding of the Applicability of Uncertainty Forecasts in the Electric Power Industry." *Energies* 2017, 10(9), 1402; doi:10.3390/en10091402

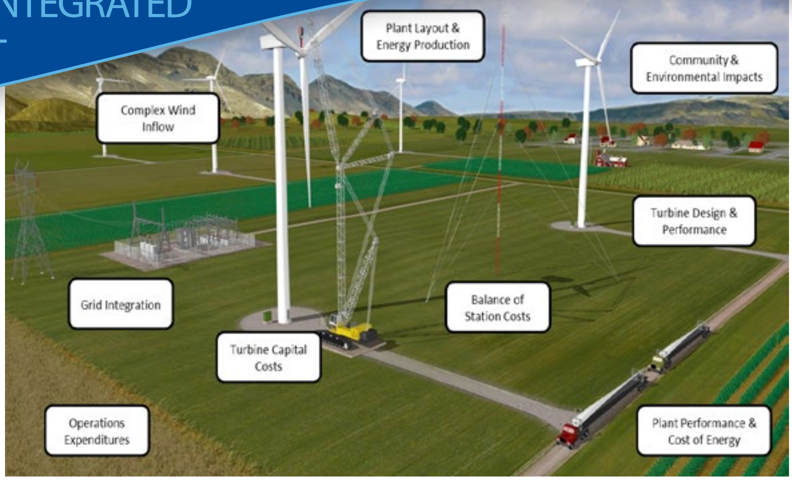
[5] J. Dobschinski, et al. (2017). "Uncertainty Forecasting in a Nutshell: Prediction Models Designed to Prevent Significant Errors." *IEEE Power and Energy Magazine*, vol. 15, no. 6, pp. 40-49, Nov.-Dec. 2017, doi: 10.1109/ MPE.2017.2729100

[6] ESIG Wind Power Forecasting Workshop, June 19-21 2017. www.esig.energy/event/2018-forecasting-workshop/

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

TASK 37

WIND ENERGY SYSTEMS ENGINEERING: INTEGRATED RESEARCH, DESIGN, AND DEVELOPMENT



Task 37 Contact and Information

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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 technological innovation has resulted in larger turbines and wind plants with lower costs of energy. However, the increasing importance of wind energy's role within the electricity sector also imposes more requirements on the performance, reliability, and cost of the technology.

To meet these requirements, industry has sought to improve the performance, reliability, and cost of turbine and plant design. However, trade-offs among competing goals require a more integrated approach. An integrated approach is needed to fully assess how a change or an uncertainty in a design parameter affects the myriad objectives in system performance and cost. Integrated systems research, design, and development (RD&D), which can be applied to both tools and methods, can improve system performance and reduce the levelized cost of energy. Nevertheless, developing such an approach poses significant challenges, both within and across organizations.

The purpose of IEA Wind TCP Task 37 is to apply a holistic, systems-engineering approach across the entire wind energy system and to improve the practice and application of systems engineering to wind energy RD&D. The Task comprises three interrelated and complementary work packages (WP):

- Guidelines for a common framework for integrated RD&D at different fidelity levels
- Reference wind energy systems
- Benchmarking Multidisciplinary Design, Analysis, and Optimization (MDAO) activities at different system levels (both turbines and plants)

PROGRESS & ACHIEVEMENTS

In 2017, significant progress was made in each work package. In WP 1, the Task moved from the disciplinary-fidelity matrices developed in 2016 (see 2016 IEA Wind TCP Annual Report) to the development of a wind turbine and plant ontology to standardize modeling interfaces for MDAO. Work began in the fall of 2017 and will continue through 2018 with publication of the first version of a wind plant ontology for MDAO.

For WP 2, the two reference turbine designs went through final stages of development and review (Figure 1). A low-wind-speed 3.X-MW land-based turbine developed by TUM and a 10-MW offshore turbine developed by DTU were reviewed in detail during the Annual Meeting held in September 2017. During the fall of 2017, industry input helped in refining and finalizing the designs, and publication of the full designs, including all the data and an IEA Wind TCP technical report, is expected in 2018. Both associated reference wind plants will be developed and completed in 2018.

For WP 3, on benchmarking MDAO activities, the first case study was completed on a single-discipline aerodynamics optimization. In a blind stage, eight organizations completed the optimization using a common problem formulation and their own unique modeling toolsets and optimization set-ups. The results were shared and discussed at the Annual Meeting, and a debugging round commenced at the end of 2017.

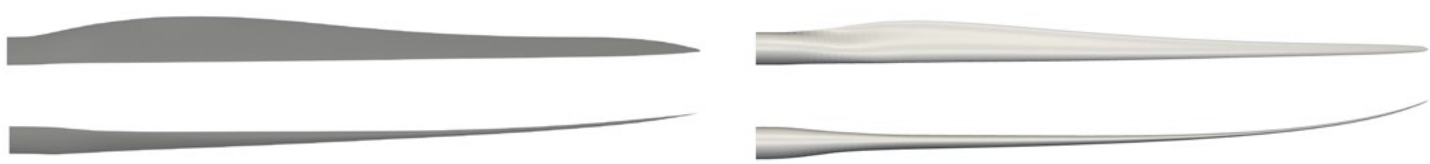

Figure 1. New IEA Wind TCP Task 37 Reference Turbine blade design top view (top) and leading-edge view (bottom) for the 3.X-MW land-based turbine (left) and the 10-MW offshore turbine (right)

In addition, Task meetings were held in conjunction with the AIAA SciTech 2017 wind energy symposium, Texas, USA and the Wind Energy Science Conference 2017 (with a dedicated track related to Task 37 work) in Lyngby, Denmark. The annual meeting was held in conjunction with the 4th Wind Energy Systems Engineering (WESE) Workshop in September 2017 at DTU Risø Campus, Roskilde, Denmark.

OUTCOMES & SIGNIFICANCE

There have been several requests from the research community and consortiums to use the reference wind turbines developed under WP 2. A wind energy start-up recently offered this comment: "IEA [Wind Task] 37 is tremendously helpful to the international wind community, especially for small companies such as mine trying to develop innovative technologies." Task 37 participants and others are using the designs for follow-on studies ranging from novel approaches to load mitigation in wind turbine blades, new materials for wind turbine blade design, and tall-tower applications for land-based technologies.

For the other work packages, guidelines and MDAO case study documents are planned for 2018 to help inform how industry integrates software for MDAO applications and how industry uses MDAO techniques in practice to design the next generation of wind turbines and power plants.

Task 37 and the WESE Workshop

The highlight of 2017 was the dissemination of work during the 4th WESE Workshop. With over 100 participants (over half from industry), the workshop showcased the state-of-the-art in systems engineering research applied to wind energy with a dedicated session to present progress reports on Task 37's work for the overall task and each work package. One industry attendee remarked, "There are two conferences I attend, Torque and the systems engineering workshop." This workshop will likely reoccur in 2019 with CENER in tentative agreement to host.

The Task's two-day Annual Meeting occurred prior to workshop with participation from wind turbine manufacturers, consultancies, and representatives from all participating countries. Detailed working sessions reviewed the status and made advancements for each work package:

- WP 1: Attendees reviewed and finalized disciplinary-fidelity matrices; the group began developing the formal ontology associated with the most common discipline-fidelities for MDAO workflows at the turbine and plant level.
- WP 2: Two reference wind turbines underwent a design review, and feedback was used to finalize those designs for publication; the offshore reference plant configuration was finalized with plans for development in 2018.
- WP 3: Results of the blind phase of the first MDAO case study (aerodynamics-only optimization) were presented and discussed; next stages for the case study and subsequent case studies were discussed.

Table 1. Task 37 Participants in 2017

Member	Participating Organizations
CWEA	Goldwind
Denmark	Technical University of Denmark (DTU) Wind Energy; Vestas Wind System A/S; Siemens Gamesa Renewable Energy
Germany	Fraunhofer IWES; Technische Universitat at Munchen (TUM); 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
United Kingdom	BVG Associates Ltd.; DNV GL; Offshore Renewable Energy Catapult
United States	NREL; Brigham Young University; GE Global Research; Sandia National Laboratories

Figure 2. The 4th Wind Energy Systems Engineering Workshop and IEA Wind TCP Task 37 Annual Meeting: DTU Wind Energy in Roskilde, Denmark, September 2017

NEXT STEPS

During the coming year, the following activities are expected to take place:

- WP 1: Release of version 1 of software guidelines for wind energy MDAO and the associated ontology
- WP 2: Publication of two reference turbines and associated reference wind power plants (land-based and offshore wind applications)
- WP 3: Publication of results from the first MDAO case study on aerodynamics, and execution of a follow-on study for structural optimization of a wind turbine blade and a case study of wind plant layout optimization

References

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

[1] Proceedings of the 4th Wind Energy Systems Engineering Workshop https://www.nrel.gov/wind/systems-engineering-workshop-2017.html

Authors: Katherine Dykes, National Renewable Energy Laboratory (NREL), United States; Frederik Zahle, Technical University of Denmark (DTU) Wind Energy, National Laboratory for Sustainable Energy, Denmark; and Karl Merz, SINTEF Energy Research, Norway.

TASK 39

QUIET WIND TURBINE TECHNOLOGY

Task 39 Contact and Information

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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. The goal of IEA Wind TCP Task 39 is to accelerate the development and deployment of quiet wind turbine technology and consolidate understanding of wind turbine sound emissions. The Task will convene an international expert panel to identify best practice in the measurement and assessment of noise and develop an IEA Wind TCP Recommended Practice that contributes to IEC standards for wind-turbine noise.

Task 39 was approved, with a three-year program, in October 2017. The Task objective is to ensure that the best available information on quiet noise technology is available to consultants, regulators, and developers to contribute to relevant international standards and government regulations. The collaboration will carry out its work in a series of focused work packages:

- Address interdisciplinary education and guidance, and support interdisciplinary discussion
- Address technical aspects of design, modeling, assessment, and measurement, including subjective effects
- Develop a recommended practice

To date, there has been broad participation in Task meetings, involving experts from 11 countries and a diversity of disciplines in industry, consultancy, and research. Remote participation and presentations in meetings, facilitated through web conferencing, have served to extend participation to a wider group of experts.

At the end of 2017, potential Task participants included: HGC Engineering and Aercoustics (Canada), CGC and Goldwind Science & Creation Windpower Equipment Co (China), Siemens, EMD International, and Danish Technical University (Denmark), Poyry (Finland), DLR, Enercon, SWE, IFB & IAG Universität Stuttgart, Senvion, and Mesh Engineering (Germany), Trinity College Dublin, RPS, and SEAI (Ireland), ECN/TNO (Netherlands), NVE (Norway), Prona SA (Switzerland), Ion Acoustics, Hayes McKenzie, Salford University, and Innogy Renewables UK (United Kingdom), and CH2M and the National Energy Renewable Energy Laboratory (United States).

PROGRESS & ACHIEVEMENTS

At the kick-off meeting, Task members agreed to:

- Develop a database of worldwide noise regulations
- Publish fact sheets on wind-turbine sound emission, propagation, and effects to meet the needs of policymakers, regulators, and the public
- Develop a state-of-the-art report on quiet wind-turbine technologies and supporting practices, research, and regulation

Task 39 participants made progress on the database and state-of-the art report, as well as presenting a proposed penalty scheme for amplitude modulation at an Institute of Acoustics conference in the United Kingdom.

The scope of the recommended practice on amplitude modulation was informed by the IEC 61400-2 MT11, which has developed a new IEC technical specification "Wind energy generation systems - Part 11-2: Measurement of wind turbine noise characteristics in receptor position." As the specification will include a definition of a procedure for measurement of amplitude modulation, Task 39's work on a recommended practice in this area will therefore be to support adoption and implementation of this new IEC technical specification.

Task Meeting No.1 was held at the Risø campus of Danish Technical University (DTU), Denmark, which included a tour of the new anechoic wind tunnel at DTU, where flow noise from wind-turbine blade sections can be measured. During the meeting, participants agreed to add to the work plan the following deliverables:

- Database linking wind-turbine measurements around the world
- Benchmarking modes of noise from wind- turbine blade profiles
- Liaise with the standards committees developing standards on wind turbine noise measurement at receptor locations (IEC 61400-11-2) and other standards in relation to propagation (e.g., ISO 9613-2)

Benchmarking of aeroacoustic computational methods using a common blade profile with a known geometry was also identified as a potential area of co-operation. The DTU representative agreed to establish cooperation with other test centers. A blade profile that is in the public domain (not subject to copyright) will need to be obtained for the project.

Figure 1. Task 39 Participants, 2017 (Source: John Mc Cann)

OUTCOMES & SIGNIFICANCE

Developing technologies and regulatory and siting processes that support the continued adoption of quiet wind turbine technologies will assist the full exploitation of available sites while maintaining public support. Recent evidence from the 2018 study highlights the influence of exogenous factors upon annoyance. IEA Wind Task 28 has already advanced the potential for enhanced community engagement to address such problems.

Task participant Franck Bertagnolio of DTU has developed a draft "*Roadmap for a wind turbine noise simulation codes benchmark*" to share among potential participants. This exercise aims to evaluate existing numerical tools that have the capability of modeling wind turbine aerodynamic noise. Such benchmarking exercises will contribute to an international convergence toward best practice in aeroacoustic simulation.

NEXT STEPS

Task 39 is open for additional participants. In the coming term, Task 39 will hold a joint meeting with Task 28 and present in a joint session at the WindEurope Global Wind Energy Summit in Hamburg in September 2018. There are strong connections between the two Tasks, and such joint meetings and presentations will serve to highlight potential synergies.

DTU, DLR, and Senvion will continue developing the scope of the aeroacoustic model benchmarking. DTU Risø has recently commissioned a state-of-the-art acoustic wind tunnel which, along with an existing facility at DLR, may be valuable in any potential technology characterization campaign, which may be included in the scope of a further sub-task on quiet wind turbine technologies.

Work will continue on the database of national regulations, the state-of-the-art report, and Task 39 fact sheets.

The Attitudes of Wind Power Project Neighbors: Task 28 and 39 Collaborated on National Acceptance Survey

Tasks 28 and 39 collaborated in a landmark international research project *National Survey of Attitudes of Wind Power Project Neighbors*. Lawrence Berkeley National Laboratory led the project with collaboration from the University of Delaware, Portland State University, the Medical School of Hamburg, RSG Inc., and the National Renewable Energy Laboratory [1].

The research found that an overwhelming majority of the residents surveyed were positively disposed to nearby wind turbines, but a small minority were negatively disposed. A similarly small minority professed annoyance at the sound of wind turbines. There were significant findings on the factors that predispose some residents near wind farms to be annoyed by such sound. Neither the distance from the nearest wind turbine nor the predicted sound level at a residence were found to be strongly correlated with annoyance. A resident's prior support for, or opposition to, a local wind farm project was found to be the strongest predictor of "very annoyed" responses.

A perception that the planning process for a wind farm project was unfair strongly correlated with both a negative attitude toward the wind farm and annoyance. These are initial findings from the project results, and a fully peer-reviewed analysis of the data will be published in 2018.

References

Opening photo: Pen y Cymoedd (Photo credit: Mike Davies)

[1] Hoen B., Rand, J., Wiser, R., Firestone, J., Elliott, D., Hübner, G., Pohl, J., Haac, R., Kaliski, K., Landis, M., Lantz, E. (2018). *National Survey of Attitudes of Wind Power Project Neighbors: Summary of Results*

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TASK 40
DOWNWIND TURBINE TECHNOLOGIES

Task 40 Contact and Information

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INTRODUCTION

Downwind turbines were once considered a promising concept to reduce levelized cost of energy (LCOE) in larger and lighter rotors, due to their lower requirements for stiffness and advantages in stability. However, downwind turbines have not succeeded in the market for decades, largely due to technical problems and lack of experience.

Advancements in design standards, design model and analysis methods, have contributed to downwind turbine development in recent years. Following the trend toward larger offshore wind turbines, there is a renewed focus on downwind turbines, with some demonstration projects being installed.

Modern design and analysis models can be verified using the accumulated data to evaluate the benefits and problems of downwind turbines. Therefore, a systematic research project on downwind turbines is necessary to further innovate wind turbine technologies and to respond to the economic needs of wind energy.

The objective of Task 40 is to coordinate international research and investigate the advantages of downwind turbine technologies. The Task expects to publish an IEA Wind TCP Recommended Practice on downwind turbine technologies, including IEC standards and national regulations, as well as journal and conference papers that include participation from industry and other end-user organizations (e.g., NGOs).

PROGRESS & ACHIEVEMENTS

IEA Wind TCP Task 40 was approved for a three-year period in June 2017. Japan and the United States participated formally in 2017. Organizations and industry from Denmark, Germany, the Netherlands, Spain, and Switzerland are anticipated to join the new Task in 2018. Additional participants are welcome.

The Task kick-off meeting was held in December 2017 for participants to update plans for the upcoming phase. The collaboration will carry out its work in a series of focused work packages.

Work Package 1 addresses model development and verification, setting up the foundation for comparisons between upwind and downwind turbines. A 2-MW baseline turbine model will be developed, which will comparable with data from recent operating experience of 2-MW turbines. These downwind turbines have experienced a wide range of operating conditions, including typhoons. The baseline turbine model can be used to compare and verify tower shadow models, nacelle-rotor interaction effects, and noise. The model can also be used to study control of downwind turbines, such as different approaches to yaw control under extreme conditions.

Work Package 2 addresses one of the most important aspects of this Task: design and LCOE. Participants will compare various LCOE benefits of downwind turbines on a relative basis and in a transparent way. Quantifying the technical and economic benefits will provide a measure of the value of innovations made possible with downwind turbines, such as blade optimization and the deployment of larger turbine sizes. The core LCOE models developed in IEA Wind Task 37 Wind Energy Systems Engineering can serve as the starting point for this work package.

Finally, Work Package 3 will develop an IEA Wind TCP Recommended Practice for Task 40. The Task coordinator and work package leaders will form a working group to develop this document, which will integrate and summarize the findings of the previous work packages.

Task 40 aims to investigate the potential benefits of downwind turbine technologies and their application in high-wind and typhoon prone areas.

Figure 1. The participants of the kick-off meeting in Tokyo, December 2017 (Photo Credit: Masataka Owada)

OUTCOMES & SIGNIFICANCE

Task 40 aims to investigate the benefits of downwind turbine technologies—particularly as they relate to the reduction of the LCOE and proliferation of offshore and onshore wind plants. Other objectives include:

- Innovate wind turbine technology
- Identify and resolve technical issues relevant to downwind turbine design
- Propose revisions to IEC standards as needed (e.g., IEC61400-1)
- Help to reshape the national regulations (e.g., identify constraining regulations and propose changes to acceptance criteria)

Task 40 will gather international thought leaders for annual meetings during the three-year project duration. The outcome of the meetings will be:

- Organize a global network that coordinates research and verification efforts
- Quantify known benefits and areas that need further research and verification
- Quantify opportunities for reducing cost of energy
- Identify potential barriers, such as changes to standards and/or regulations
- Identify opportunities for collaborative research and demonstration projects
- Identify perceived technical risks and propose resolutions
- Update and expand the knowledge basis for downwind turbines

Table 1. Task 40 Participants in 2017

Member/Sponsor	Participating Organizations
Japan	National Institute of Advanced Industrial Science and Technology (AIST); Nippon Kaiji Kyokai (ClassNK); Hitachi, Ltd. (Hitachi); Kyushu Univ. (KU); The Univ. of Tokyo (UTokyo); Wind Energy Institute of Tokyo, Inc. (WEIT)
United States	The National Renewable Energy Laboratory (NREL)

NEXT STEPS

Task 40 updated their work plan following the kick-off meeting in 2017. The work plan is now ready for approval from IEA Wind ExCo members. Task 40 will formally begin once the work plan is approved in 2018, with more than five countries expected to participate. The Task will commence with Work Package 1: Model development and verification.

References

Opening photo: Downwind and upwind turbines in Tawara, Japan (Photo credit: Toro Nagao)

Authors: Shigeo Yoshida, Kyushu University, and Masataka Owada, Wind Energy Institute of Tokyo, Japan.

Austria

Table 1. Key Statistics 2017, Austria	
Total (net) installed wind power capacity	2,844 MW
Total offshore capacity	0 MW
New wind power capacity installed	196 MW
Decommissioned capacity (in 2017)	0 MW
Total electrical energy output from wind	7 TWh
Wind-generated electricity as percent of national electricity demand	11%
Average national capacity factor	26%
Target	100% renewable electricity by 2030

OVERVIEW

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 2017, Austria installed 63 turbines with a capacity of 196 MW, compared to 75 turbines (228 MW) in 2016. By the end of 2016, more than 2,800 MW were installed in Austria. This capacity is able to produce 7.0 TWh, which accounts for 11% 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 7,500 MW with 22.5 TWh by 2030.

MARKET DEVELOPMENT

Wind power installations significantly proliferated following the 2012 Okostromgesetz (Green Electricity Act, GEA). This law established a 2020 target of 2,000 MW of 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 2018 was 0.0820 EUR/kWh (0.098 USD/kWh). For 2017, it was fixed at 0.0895 EUR/kWh (1.107 USD/kWh).

The market price collapse significantly lowered the annual budget for green electricity. This has created a project queue, with projects waiting until as long as 2025 for new funding.

In 2017, a small amendment to the GEA 2012 lowered pressure and political uncertainty by allocating 45 million EUR in additional funding (54 million USD), this allows the installation of about 120 turbines (350 MW) that have already been approved. However, tariffs for those projects are subject to a deduction of up to 12% depending on their original ranking in the project queue.

National Targets & Policies Supporting Development

The GEA 2012 preserved the existing targets of 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). This study was updated in 2018. If all wind turbines which have already been approved are installed, the total wind power capacity will reach 3900 MW (annual production of 9 TWh). By 2030, a total capacity of 7,500 MW (annual production of 22.5 TWh) could be achieved [1].

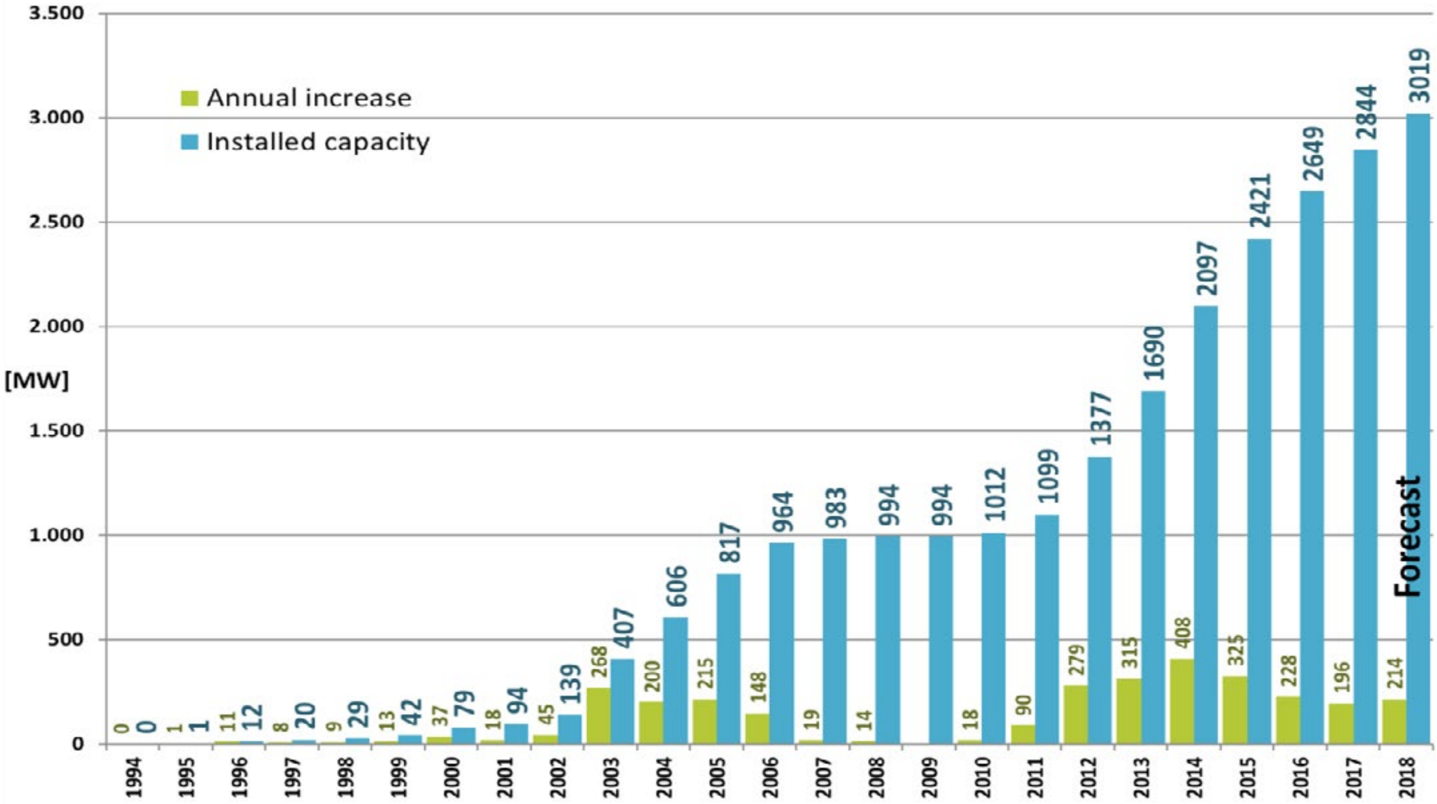

Figure 1. Wind power capacity in Austria from 1994-2017

The 2002 GEA triggered investments in wind energy from 2003-2006. 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; 0.116 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; new projects only get a purchase obligation and a FIT if they contract with the Okostromabwicklungsstelle (OeMAG), the institution in charge of buying green electricity at the FIT and selling it to the electricity traders.

The OeMAG's contracts with green electricity producers are limited to the available funds for new projects — a budget that started with 50 million EUR/yr (60 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 (1.2 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 Okostromverordnung/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 (based on available funds for new projects). For 2017, the tariff was fixed at 0.0812 EUR/kWh (0.0974 USD/kWh). In 2017, a small amendment to the GEA 2012 allocated 45 million EUR (54 million USD).

On average, around 480 million EUR (576 million USD) were invested annually from 2013-2017 (including investments of wind power operators for power grid expansion). Wind power was the fourth largest industry investment during this period. The current waiting queue would free investments of 1 billion EUR (1.2 billion USD), create 4,250 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.

Progress & Operational Details

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.

With a capacity of 2,844 MW in 2017, the annual production of all Austrian wind turbines accounts for 11% of the Austrian electricity demand and avoids about 4.3 million tons of CO_2. The estimated capacity by the end of 2018 is 3,019 MW.

Most wind turbines are in Lower Austria (1,535 MW), followed by Burgenland (1,026 MW), Styria (227 MW), Upper Austria (47 MW), Vienna (7 MW), and Carinthia (1 MW) (Table 2).

Table 2. Capacity and Number of Turbines by Federal State

Federal State	Capacity (MW)	Turbines
Lower Austria	1,535	693
Burgenland	1,026	426
Styria	227	100
Upper Austria	47	30
Vienna	7	9
Carinthia	1	2
Total Austria	**2,844**	**1,260**

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. In 2017, the tallest turbines were the 203-m Vestas V126 in lower Austria.

Matters Affecting Growth & 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 (107 million USD) in 2011 to more than 200 million EUR (240 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 by June 2017 to the GEA 2012 could have reduced the pressure and political uncertainty. Nevertheless, there are still 200 wind turbines (650 MW) in the current queue waiting until 2023 for new funding. These projects, which sum up to an investment of 1 billion EUR (1.2 billion USD), would create 4,250 wind industry jobs, and would raise the wind share to nearly 15% of electricity consumption. Since those projects have already been approved by the legal authorities, significant investors might be frustrated. The amendment finally came into force in July 2017, however further funding is still required. Otherwise, the net installed capacity will decrease in the coming years.

R,D&D ACTIVITIES

National R,D&D Priorities & Budget

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, aims to elaborate on an icing map of Austria and observe icing events at wind turbines using an innovative imaging method. 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.

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 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. This cooperation will continue until the end of February 2019.

IMPACT OF WIND ENERGY

Economic Benefits & Industry Development

The Austrian wind power market is made up of wind turbine operators, planning offices, and component suppliers for international wind turbine manufacturers. In 2017 (the latest available statistics), the annual turnover of existing wind parks operators was over 550 million EUR (660 million USD).

Austria's wind energy industry includes more than 180 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, and Austrian 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 454 million EUR (545 million USD).

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- (and 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.

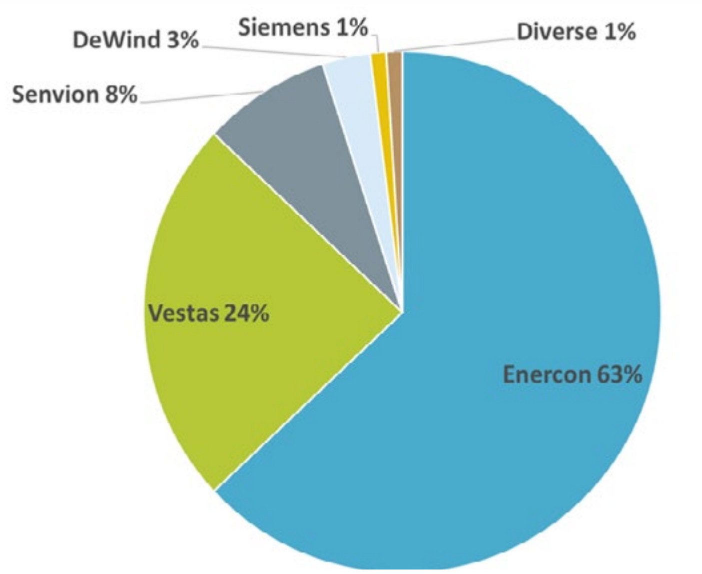

Figure 2. Turbine supplier market share by installed capacity

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 from the software, service, and component sector, which is partially transferred from the automotive and aerospace industry.

The recently-published scientific paper *Stromzukunft Österreich 2030* quantifies the total investment costs as 1,350 to 1,570 EUR/kW (1,620 to 1,884 USD/kW) and the O&M costs as 36 to40 EUR/kW (43 to 48 USD/kW) per year.

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 2017, and the situation for wind isn't likely to improve in 2018.

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Opening photo: Oberzeiring wind park, Austria
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Author: Florian Maringer and Patrik Wonisch, Austrian Wind Energy in Association and Andreas Krenn, Energiewerkstatt, Austria.

Belgium

Table 1. Key Statistics 2017, Belgium		
Total (net) installed wind power capacity	2,843	MW
Total offshore capacity	877	MW
New wind power capacity installed	165	MW
Decommissioned capacity (in 2017)	0	MW
Total electrical energy output from wind	6.346	TWh
Wind-generated electricity as percent of national electricity demand	7.58%	
Average national capacity factor	25.48%	
National wind energy R&D budget	2.73 mil EUR; 3.27 mil USD	
Target	13% of renewables by 2020 in final gross energy consumption	

OVERVIEW

The federal government began the first Belgian offshore wind park in the North Sea in 2003, and in 2004 created a 156-km2 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 2017, 232 offshore wind turbines were operational—producing 2,867 TWh/yr and providing electricity for approximately 8,000,000 families.

Belgium is a frontrunner when installed capacity is considered in relation to 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.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

In general, Belgium's renewable energy policy is aligned with the EU 2020 targets. Belgium's land-based and offshore wind energy developments are essential for both 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).

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

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 amended in 2014 and 2016. Purchase agreements must be approved by the regulator, CREG. Purchase obligations apply for a period of 22 years but may not exceed the depreciation period.

Belgium introduced changes to the formula for the levelized cost of wind energy (LCOE) to address the risk of overcompensation. On 27 October 2017, the federal government took a decision regarding the LCOE for the remaining parks: Mermaid, Northwester 2, and Seastar. These three parks shall be built at an LCOE of 79 EUR/MWh (94.8 USD MWh). The period of support is fixed at 16 years, potentially extendable for one year in case of low wind circumstances.

Progress & Operational Details

Offshore wind-generated electricity first began in 2009 and progressed rapidly to a total of 877 MW in 2017. 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 1,966 MW in 2017. Land-based wind is on track to reach its 2020 objectives after much progress during the last few years (Table 2).

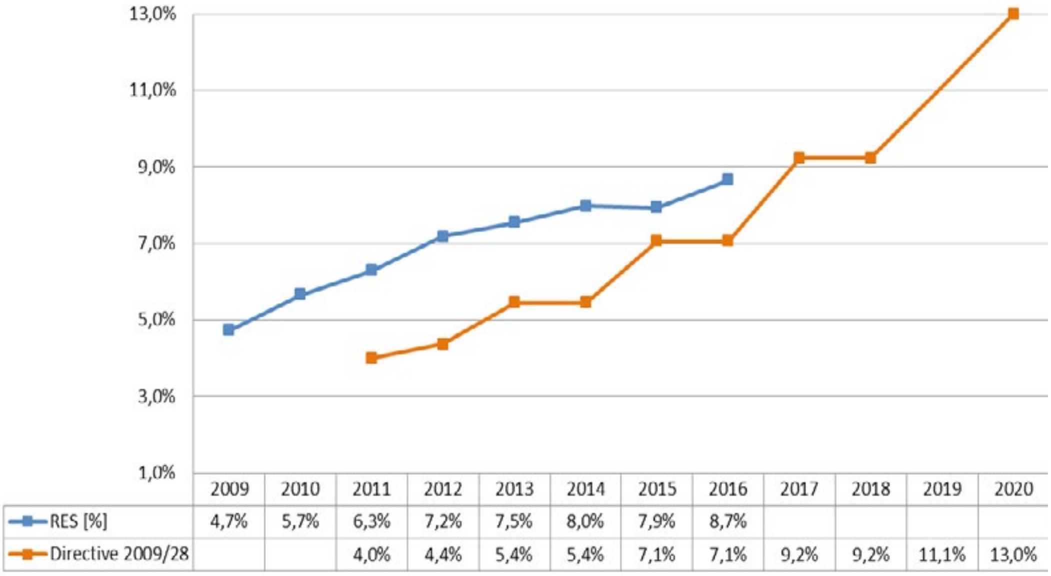

Figure 1. Percent of renewable energy share in Belgium's gross final consumption [1]

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 are unavailable for land-based wind parks.

Matters Affecting Growth & 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.

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, because of their relatively high availability, offshore wind resources provide the most potential, according to an IEA in-depth review in 2015.

R,D&D ACTIVITIES

National R,D&D Priorities & Budget

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 for clearly tailored storage.

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

Table 2. Wind Power Capacity and Production [1]

	2009	2010	2011	2012	2013	2014	2015	2016	2017
Offshore Wind Capacity and Production									
Offshore power capacity (MW)	32	197	197	381	708	708	712	712	877
Offshore electricity production (GW)	0.082	0.190	0.709	0.854	1.540	2.216	2.613	2.390	2.876
Capacity factor (%)	29.7%	11.0%	41.2%	25.6%	24.8%	35.8%	41.9%	38.3%	37.4%
Total Electricity Production									
Total electricity production (GW)	91.235	95.189	90.241	82.923	83.526	72.687	70.648	83.133	83.722
Wind-generated electricity (GW)	0.996	1.292	2.312	2.751	3.687	4.614	5.574	5.191	6.346
Electricity demand met by wind energy (%)	1.09%	1.36%	2.56%	3.32%	4.41%	6.35%	7.89%	6.24%	7.58%

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.

The Belgian government invested 2.728 million EUR (3.273 million USD) in offshore and land-based wind in 2017. This is less than the 4.299 million EUR (5.158 million USD) in 2015, mainly due to the reduction of the budget for unallocated wind energy (from 3.503 million EUR in 2015 to 0.068 million EUR in 2016; 4.20 million USD in 2015 to 0.081 million USD in 2016). On the other hand, the budget for wind energy systems and other technologies increased from 0.543 million EUR (0.652 million USD to 2.453 million EUR (2.943 million USD).

Figure 2. Nobelwind wind farm located in the Belwind concession area in the North Sea approximately 47 km from shore (Source: Nobelwind, http://nobelwind.eu/)

National Research Initiatives & Results

Belgium's wind industry includes:

- Manufacturing companies such as Xant, which produces small- and medium-sized wind turbines
- Component suppliers such as ZF Wind Power, CG Power, Sky Man, Monitoring Solutions
- Operators such as OWI-lab, VJI, Laborelec

In the public sector, we have a large wind-energy research community, including Universiteit Gent, Katholieke Universiteit Leuven, ULB, Universite Mons, Universite de Liege, Sirris, BMM, and Laborelec.

Test Facilities & Demonstration Projects

OWI-lab's climatic test facility focuses on offshore wind R&D [3]. This lab invested 5.5 million EUR (6.6million 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 innovative 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].

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 and 2017, on behalf of Belgium, Sirris 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.

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)	30	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**		

Note: [a] Total Area (without security zone); [b] +20 MW wave energy; [c] Mermaid and Northwester

Another international collaboration program is the North Seas Energy Cooperation. 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 Maros Sefcovic, and Commissioner for Climate Action and Energy Miguel Arias Canete. Belgium was president of the initiative until September 2017, followed by a Dutch presidency who handed over to Denmark in June 2018. During the DG meeting in December all DG's agreed to monitor progress, get an overview of the work, a 'roadmap' per Support Group, including deliverables and timetables till mid-2019.

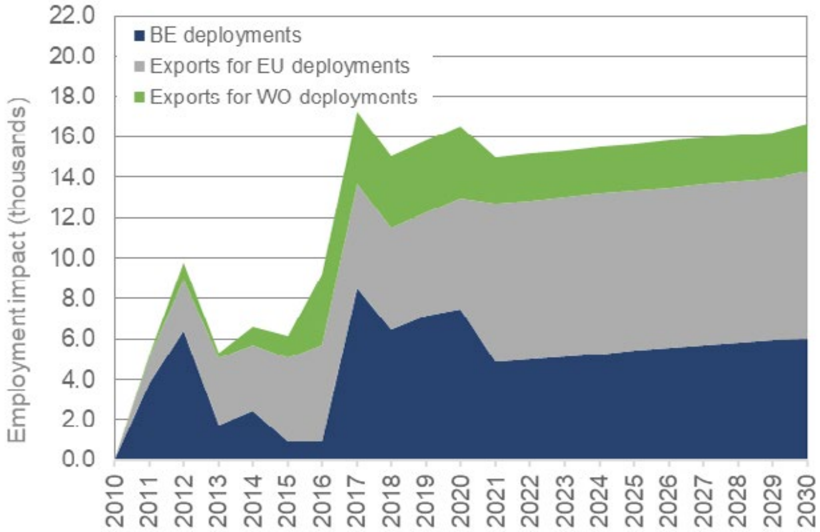

Figure 3. Total employment impacts from deployment in Belgium (BE), in Europe (EU), and in the rest of the world (WO), including construction and operations, both direct and indirect impacts [2]

IMPACT OF WIND ENERGY

Economic Benefits

The wind energy sector creates excellent economic opportunities. 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].

Environmental Impact

In addition to adding sustainable energy capacity, offshore wind energy developments also increase biodiversity, specifically organisms such as corals and plants 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.

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.

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Opening photo: Offshore wind turbine in Belgium

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Canada

Table 1. Key Statistics 2017, Canada

Total (net) installed wind power capacity	12.24 GW
Total offshore capacity	0 GW
New wind power capacity installed	0.34 GW
Decommissioned capacity (in 2017)	0 GW
Total electrical energy output from wind	30.7 TWh
Wind-generated electricity as percent of national electricity demand	5.2%
Average national capacity factor	29.4%
National wind energy R&D budget	4.17 mil CAD; 2.77 mil EUR; 3.32 mil USD

OVERVIEW

In 2017, Canada added 341 MW of wind power capacity, bringing the total installed wind power capacity to 12,239 MW. The five-year annual growth rate of wind power capacity is 15%. There are currently 295 wind farms operating across the country, including utility-scale projects in two of the three northern territories.

Canada installed about half as much new capacity in 2017 as in 2016 (341 MW and 681 MW, respectively); this reduction is a result of policy uncertainty in several key regions in Canada, as well as a general slowing of load growth across the country. Wind energy continues to be one of the lowest cost options for new electricity supply in Canada. This is evidenced by the record low weighted average bid price of 37 CAD/MWh (25 EUR/MWh; 29 USD/MWh) from the province of Alberta's request for proposals (RFP) process for new renewable energy capacity. Despite originally seeking 400 MW of wind, the Alberta Electricity System Operator (AESO) entered into contracts for 600 MW of new wind power capacity.

Western Canada continues to have the highest wind energy growth potential in the near term, with an anticipated 6,900 MW of new renewable power capacity by 2030—a significant portion of which is expected to come from wind.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

Under the 2015 Paris Agreement on climate change, Canada committed to reducing greenhouse gases (GHG) 30% below 2005 levels by 2030. The Pan-Canadian Framework on Clean Growth and Climate Change was developed to meet Canada's emissions reduction targets while growing the economy and building resilience, which includes carbon pricing [1].

In December 2017, the government gave provinces until the end of 2018 to submit their own carbon pricing plans before a national price is imposed. The minimum 2018 carbon price will start at 10 CAD/tonne (6.6 EUR/tonne; 8.0 USD/tonne), rising to 50 CAD/tonne (33.2 EUR/tonne; 39.8 USD/tonne) by 2022.

While there are no national targets for renewable energy, many provinces have set renewable energy targets, including Alberta (30% electricity used by 2030), New Brunswick (40% electricity used by 2020), Nova Scotia (40% of electricity produced by 2020), and Quebec (25% increase of 2013 overall renewable energy output by 2030) [2-5].

Saskatchewan has a target of 50% renewable energy capacity by 2030, which includes approximately 1,900 MW of new wind power [6]. Ontario released its 2017 Long-Term Energy Plan (LTEP), a 20-year roadmap for Ontario's electricity sector [7]. The plan forecasts increased electrification and use of renewable and low-carbon technologies, but remains agnostic concerning supply options. Prince Edward Island released its 10-year strategy, calling for 70 MW of new wind power capacity [8].

The 2017 federal budget includes a role for wind energy and other renewables in the reduction of diesel use in indigenous communities. The Northwest Territories Government has set a goal to reduce GHG emissions from diesel-generated electricity by 25% relative to 2015 levels [9]. Many of the larger provincial incentive programs for new renewable energy projects have now expired; only one active community-scale program remains, New Brunswick's Community Renewable Energy program, which allows for projects up to 40 MW.

New wind power capacity is exclusively being procured through competitive processes. In December, the Government of Alberta announced the results of Round 1 of the Renewable Electricity Program (REP), which delivered 600 MW of wind power capacity at a weighted average bid price of 37 CAD/MWh (25 EUR/MWh; 29 USD/MWh)—a new record in Canada for the lowest renewable electricity pricing. Saskatchewan launched a competitive process to procure up to 200 MW of wind power capacity; announcements of successful projects are expected in 2018.

Progress & Operational Details

Ten wind power projects contributed to 341 MW of new wind power capacity in 2017—an investment of approximately 800 million CAD (530 million EUR; 636 million USD). Four out of five new wind farms larger than 10 MW featured turbines of three megawatts or greater. The 179-MW Meikle Wind Farm came online in British Columbia as the province's largest, consisting of 26 GE 2.75-MW-120 and 35 GE 3.2-MW-103 turbines. Similarly, the 100-MW Belle River project in Ontario commissioned 40 Siemens SWT 3.2-MW-113 turbines.

The capital cost for the 2017 Meikle Wind Farm was reported to be roughly 2.2 million CAD/MW (1.5 million EUR/MW; 1.8million USD/MW) and is expected to create 0.15 full-time equivalent (FTE) positions per turbine, typical for large wind farms. Five of the new projects commissioned in 2017 included significant ownership stakes from Aboriginal Peoples, municipal corporations, or local owners.

Ownership of renewable energy projects by Indigenous groups continues to grow. A national survey conducted by Lumos Clean Energy Advisors found that Indigenous groups have interest in 152 medium- to large-scale wind, solar, hydro, and bioenergy clean energy projects, and predicts another 50-60 will be commissioned over the next five to six years [10].

Nearly half of the 105 First Nations in British Columbia are involved in the clean energy sector; however, for 61% the biggest barrier they face is a lack of opportunity to sell power to the provincial utility [11]. A recent study by Western University showed higher levels of acceptance for profit-sharing, community-based projects [12].

The deployment of wind energy in northern and remote communities has been gaining interest in recent years in Canada. The Yukon government approved a proposal for a 2.7-MW wind farm at Haeckel Hill, expected to be in operation by 2019. The Northwest Territories Government is currently studying the feasibility of using wind turbines and energy storage devices in the Town of Inuvik [13].

Direct community benefits, in addition to property taxes and lease payments, are common in new projects. Belle River Wind committed 6 million CAD (4.0 million EUR; 4.8 million USD) to the community of Lakeshore, Ontario as part of a long-term Community Benefit Program, including an initial 2 million CAD (1.3 million EUR; 1.6 million USD) and an annual contribution of 200,000 CAD (133,000 EUR; 159,000 USD) for 20 years.

Matters Affecting Growth & Work to Remove Barriers

Canada is projected to install up to 6.9 GW of new wind power capacity from 2017 to 2030 (based on current policies) as the market shifts westward to Alberta and Saskatchewan. The market for new wind power in eastern Canada has been declining through a combination of low load growth, a largely decarbonized electricity sector in many provinces, and fading political support. In Ontario, peak demand is expected to continue to decline in the near term [14].

A number of Canadian energy producers and suppliers are making efforts to capitalize on clean energy goals set by several states in the northeastern United States. The year saw several Canadian companies bid in the Massachusetts clean energy RFP, calling for 9.45 GWh of clean energy annually, with wind, hydro, and transmission projects from Quebec and Atlantic provinces.

Figure 1. Nergica (previously TechnoCentre éolien) research site in Rivière-au-Renard, Québec, Canada, with Senvion MM92 CCV wind turbines, 16 kW of solar PV panels, a microgrid test bed with small wind turbines, diesel

National R,D&D Priorities & Budget

Several new programs and initiatives were announced in 2017 as part of the Canadian government's overall clean growth agenda, which includes a Mission Innovation commitment to doubling R,D&D spending from 2015 to 2020. Most relevant to the wind industry is the 49 million CAD (32 million EUR; 39 million USD) funding for the Energy Innovation Program from April 1, 2016 to March 31, 2019 to support clean technology research and development.

The Green Infrastructure programs, including the Emerging Renewable Power Program, have pledged 200 million CAD (133 million EUR; 159 million USD) over four years to support commercial renewable energy technologies not yet deployed in Canada, including offshore wind development. Other components of the Green Infrastructure program, including 100 million CAD (67 million EUR; 80 million USD) for Smart Grid demonstration and deployment projects, will indirectly support the wind industry by seeking to further integrate renewable energy sources into the bulk electricity system.

National Research Initiatives & Results

A federal government funded study on wind farm performance in cold climates demonstrated an average production penalty of 3.9% during winter months relative to summer months [15]. The study covered 23 wind farms across Canada from 2010-2016. Extrapolating the results to the entire Canadian wind fleet yielded an estimated annual energy loss of 959 GWh, and annual financial loss of 113 million CAD (75 million EUR; 90 million USD).

The 2016 federal budget announced 2.5 million CAD (1.7 million EUR; 2.0 million USD) over two years to facilitate regional dialogues and studies to identify key large electricity infrastructure projects that can significantly reduce GHG emissions in the electricity sector and meet provincial climate change objectives. Two regional dialogues, one in Western Canada and one in Atlantic Canada, have been established under the name Regional Electricity Cooperation and Strategic Infrastructure (RECSI) initiative. Results are expected in 2018.

Test Facilities & Demonstration Projects

Research results for 2017 from Gaspé, Quebec-based Nergica include:

- Conducting a performance assessment of an ice protection system
- Developing an alignment system for nacelle-mounted wind vanes
- Developing a forecasting model for icing-induced losses in Canada
- Establishing a research program for the smart integration of renewable energies and storage technologies onto microgrids
- Developing a drone-based turbine component inspection method

Further details are available in Nergica's annual report [16].

The Wind Energy Institute of Canada (WEICan), located at North Cape, Prince Edward Island (PEI), is a wind energy research and testing institute with two major research streams: Grid Integration of Wind, and Asset Management/Service Life Estimation. Through a federal government-sponsored research program, WEICan employed its 10-MW wind farm and energy storage test bed to undertake "service scenarios," demonstrating various uses for wind energy.

Three service scenarios have been completed to date, one of which was completed in 2017. The 2017 test was intended to demonstrate their wind plant's ability to provide secondary frequency regulation by following an Automatic Generator Control (AGC) set point signal provided by a Canadian utility. The ability to follow an AGC signal was quantified using a "Performance Score," represented by a number between zero and one, where a score of one indicates a perfect signal-following generator [17]. During the test, the prevailing wind was above the turbine's rated wind speed, yielding a performance score of 0.95 (Figure 3) [18]. Another test, evaluating the wind plant response when the wind speeds are below rated wind speed, will be conducted in 2018.

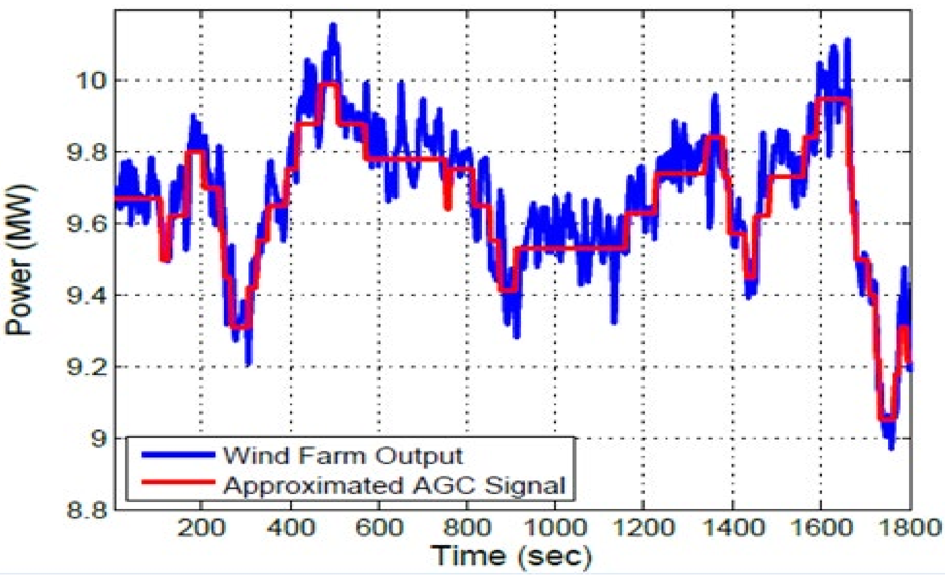

Figure 3. Results of the 30-minute automatic generator control (AGC) signal-following test undertaken at the 10-MW Wind Energy Institute of Canada (WEICan) wind plant. During the 30-minute test, WEICan measured the capability of its wind plant to follow an AGC signal provided by a Canadian utility.

Figure 2. Castle River Wind Farm, Alberta featuring Vestas V47 turbines (Photo credit: Canadian Wind Energy Association (CanWEA)/Bryan Passifiume)

Collaborative Research

Canada currently participates in the following IEA Wind Technology Collaboration Programme tasks:

- Task 19 Wind Energy in Cold Climates
- Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power
- Task 32 Wind Lidar Systems for Wind Energy Deployment
- Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN)

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

IMPACT OF WIND ENERGY

Environmental Impact

Results of the Pan-Canadian Wind Integration Study (PCWIS) show that significant amounts of GHG emissions can be avoided through increased penetration of wind energy onto the electrical grid [19].

Under the modeled 20% wind penetration scenario, CO_2 intensity is estimated to decrease from 0.14 tonnes/MWh to 0.12 tonnes/MWh compared to the 5% business as usual case, a reduction of 12.3 million tonnes of CO_2 annually. SO_x intensity would be reduced from 0.19 to 0.18 kg/MWh, avoiding 3.6 thousand tonnes of SO_x emissions, and NO_x intensity would drop from 0.04 to 0.03 kg/MWh, avoiding 2.9 thousand tonnes of NO_x emissions.

Economic Benefits & Industry Development

Estimates of total employment and economic activity in the wind energy sector at a national level are difficult to obtain. A study by the Canadian Wind Energy Association (CanWEA) shows that Alberta's wind energy sector is expected to deliver 3.7 billion CAD (2.5 billion EUR; 2.9 billion USD) in local spending and almost 15,000 job-years of employment by 2030 [20].

Growth of domestic turbine component manufacturing capability was mixed during 2017. Siemens shut down its plant in Tillsonburg, Ontario, cutting roughly 340 jobs. Meanwhile, LM Wind Power announced plans to expand its blade manufacturing facility in Gaspé, Quebec, adding 265 jobs.

This expansion received financial support of roughly 7.2 million CAD (4.8 million EUR; 5.7 million USD) from the Government of Quebec.

Lastly, Groupe FabDelta received a federal loan of 1 million CAD (0.66 million EUR; 0.80 million USD) to retrofit an industrial building to manufacture wind turbine hubs and signed an agreement to supply hubs for the 147-MW Mont Sainte-Marguerite project currently under development in Quebec.

NEXT TERM

According to CanWEA, roughly 625 MW of new wind power capacity is expected to come online in 2018. The majority of this new capacity will be located in Ontario and Quebec, with a few smaller projects in British Columbia and Nova Scotia.

The North American Renewable Integration Study (NARIS), a collaborative effort between the federal governments of Canada, México, and the United States, is analyzing pathways to modernize the North American power system through the efficient planning of transmission, generation, and demand. NARIS will examine the interconnection of the three power systems, from planning through operation and balancing at 5-minute resolution, and will assess strategies and technologies to enable high penetrations of renewables. Final results are slated for 2019.

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Opening photo: Castle Rock, Alberta ENERCON E-70 E2 (Photo credit: ENERCON Canada Inc.)

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Chinese Wind Energy Association (CWEA)

Table 1. Key Statistics 2017, China

Total (net) installed wind power capacity	188.4 GW
Total offshore capacity	2.8 GW
New wind power capacity installed	19.7 GW
Decommissioned capacity (in 2017)	---
Total electrical energy output from wind	305.7 TWh
Wind-generated electricity as percent of national electricity demand	4.8%
Average national capacity factor	21.3%
National wind energy R&D budget	10 mil CNY; 1.3 mil EUR; 1.5 mil USD
Target	210 GW by 2020

OVERVIEW

China continues to have the highest wind power capacity in the world, although the pace of growth slowed in 2017. 19,659 MW of new wind power capacity was installed, representing a 15.9% decrease in growth from last year. Accumulated capacity increased to 188,390 MW.

Grid-connected capacity increased to 164,000 MW with the addition of 15,030 MW installed in 2017. New wind power capacity accounted for 9.2% of installed power capacity nationwide. New installations in the mid-eastern and southern regions account for 50% of the total new installation capacity.

Wind power remains the third largest generation source in China, following thermal and hydro-electricity sources. The average full-load-hour of wind power was 1,948 hours in 2017, an increase of 203 hours from 2016. Wind-generated electricity totaled 305.7 TWh, increase 26.3% over the previous year. Wind-generated electricity accounted for 4.8% of the total electricity generation, an increase of 0.7% over 2016. The average wind curtailment rate was 12%, a decline of 3% compared to 2016.

In 2017, the Chinese government issued a series of policies and regulations to reduce wind curtailment and promote the development of distributed wind power. In addition, Chinese companies made progress in R&D, including wind energy developments in low wind-speed areas and offshore wind energy generation.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

In 2016, the Chinese government released the 13th Five-Year Plan on Renewable Energy Development (2016-2020). This plan set several targets to promote the energy transition in China. By the end of 2020, installed wind power capacity will grow to more than 210 GW, and installed offshore wind power capacity will total approximately 5 GW.

In 2017, the National Energy Administration (NEA) issued guidelines on implementation of the 13th Five-Year Plan. These guidelines included measures promoting assumption, reducing cost, and more to ensure the completion of the five-year plan. In addition, the guidelines updated wind energy construction targets for the provinces from 2017 to 2020. According to the plan, new installations will reach 110 GW—significantly more than the previous five-year plan target of 79 GW. Henan and Hebei will be the fastest growing provinces, with the new installation of 12 and 11 GW.

Hebei, Shandong, Jiangsu, Shanghai, Guangdong and others also set offshore wind development targets for this five-year plan period. In Jiangsu and Guangdong provinces, installed offshore wind power will reach 3.5 GW and 2 GW, respectively.

The NEA also issued an implementation plan, which set targets for reducing curtailment of wind, solar, and hydropower power generation. The plan presented some concrete measures, such as: improving the management mechanism of target assessment; promoting renewable energy power market transactions; implementing renewable energy electricity quotas; and enhancing power transmission capacity. Under this plan, the problem of wasted renewable energy will be solved by 2020.

In 2017, the NEA issued requirements aimed at speeding the construction of distributed wind power projects. It presented rules for distributed wind power development

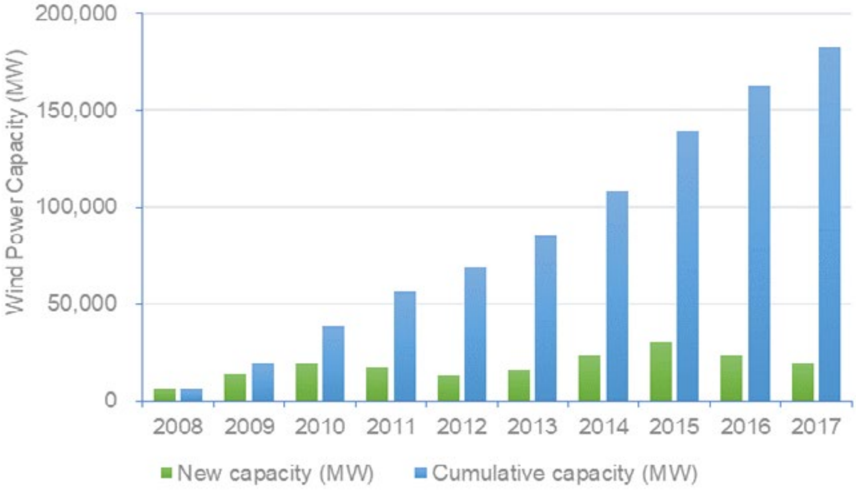

Figure 1. New and accumulated installed wind power capacity in China, 2008-2017 (Source: CWEA)

and encouraged the government's department of energy to simplify project approval procedures. Distributed wind power project construction will not be restricted by the annual limit for new installations.

In 2017, the National Development and Reform Commission (NDRC), Ministry of Finance, and NEA implemented a voluntary subscription trading system for renewable energy certificates (RECs). The REC system will stimulate renewable energy consumption by creating a new subsidy mechanism for renewable energy development in China.

Progress & Operational Details

By the end of 2017, China installed 19,659 MW of new wind power capacity (exclusive of Taiwan). This accounted for 37% of new global wind capacity for the year. The accumulated wind power capacity in China reached 188,390 MW, accounting for 34.9% of wind power capacity worldwide, maintaining the highest wind power capacity in the world.

Compared to 2016, the rate of new wind-power installations decreased by 15.9%, although cumulative installed power capacity increased by 11.6%. Wind power generation reached 306 TWh in 2017—4.8% of total electricity generation.

A total of 9,310 new wind turbines were installed in 2017, bringing the national total of operating turbines to 114,244. The average capacity of newly installed wind turbines was about 2.1 MW, an increase of 7.3% since 2016. The average capacity of all installed wind turbines increased to 1.7 MW.

The five provinces with the most new installed capacity were:

- Hebei (2.1 GW)
- Shandong (1.5 GW)
- Jiangsu (1.5 GW)
- Inner Mongolia (1.4 GW)
- Qinghai (1.3 GW)

Together, these accounted for 40% of the new capacity nationwide. The middle, eastern, and southern regions of China account for 50% of new installations. The average weighted full load hours of operating wind farms totaled 1,948 hours, an increase of 203 hours as compared to 2016.

Factors that influence cost of wind energy include levels of wind resources, construction conditions, mainstream wind turbine 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. If resources and environmental benefits are taken into consideration, the cost of wind power is nearly equal to that of coal-fired power generation.

Matters Affecting Growth & Work to Remove Barriers

Integration and consumption are still significant problems limiting wind power development in China. Wind curtailment continues to be the main restriction on wind power development.

The annual curtailed wind-generated electricity is 42 TWh. Gansu (33%), Xinjiang (29%), Jilin (21%), and Inner Mongolia (15%) are the four provinces with the highest wind curtailment rates in China. The government took some measures in 2017 to resolve this problem, including increasing peak regulation capacity and encouraging inter-provincial compensation. Consequently, the wind curtailment rate reduced 15.7% since 2016.

Because feed-in tariffs can increase the financial burden and the resulting deficit can sap the motivation of wind power developers, work to perfect market mechanisms is one of the most important measures. In 2017, the REC system began to be implemented; this system allows wind power producers to get extra income from the voluntary trade of RECs, which can cover these losses. Also, the corresponding feed-in tariff from government will be removed.

The higher power price made it harder for wind power to compete with coal-fired generation. To drive cost reduction of wind power and increase market competitiveness, the NEA carried out wind-power parity demonstration work.

In 2017, 13 projects were selected to verify the availability of the same transaction price as coal-fired generation. These projects were distributed throughout Hebei, Gansu, Xinjiang, Heilongjiang, and Ningxia provinces in China's "Three North" areas (northwest China, north China, and northeast China).

National R,D&D Priorities & Budget

In 2017, the Ministry of Science and Technology of the People's Republic of China launched the National Quality Infrastructure (NQI) Research Program.

The program, which includes 76 tasks, began implementation in2017 and aims to improve the innovation capability of NQI in China. The total budget is above 700 million CNY (89.7 million EUR; 107.6 million USD), and the budget for renewable energy is above 10 million CNY (1.3 million EUR; 1.5million USD). Two research projects are related to wind power:

- **Testing, monitoring, and evaluation technology of key renewable energy equipment in service** including detective techniques without disassembly for key mechanical parts of wind turbines; early damage and operation condition monitoring technologies; and key battery storage technologies.
- **Quality evaluation technologies for renewable energy and related products**, including reliability design and evaluation of wind turbines. This project explores quality evaluation technology for the whole production process of key components of wind turbines, and evaluations of performance, operational reliability, and residual life of wind turbines.

The expected results of this project include:

- New testing and monitoring methods and devices for wind energy and photovoltaic power generation equipment
- A diagnostic system for wind turbine blade defects
- A data analysis system for wind turbine operations
- Set standards on the reliability index and computing methods
- Set standards for methods of evaluating the power generation performance of wind turbines
- Set standards for manufacturing process quality evaluation of wind turbine blades, gearboxes and generators
- An operating condition analysis and intelligent diagnostic system for photovoltaic power generation systems
- An evaluation database for the sustainable development of biomass energy production.

In 2017, the budget of the NQI Project for renewable energy was about 3 million CNY (0.4 million EUR; 0.5 million USD). In 2018, most will support the Key Program of the research

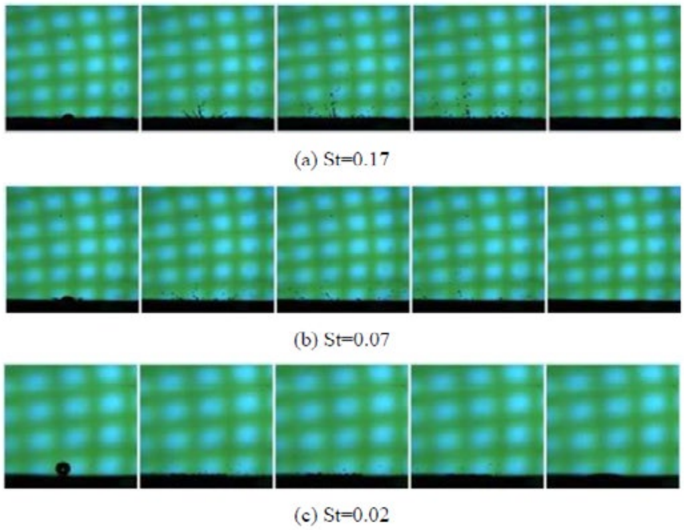

Figure 3. Droplet impingement and splashing on surfaces of different roughness

on renewable energy and hydrogen energy, including six research directions of: solar energy; wind energy; biomass energy; geothermal and ocean energy; hydrogen energy; and renewable energy coupling and system integration technology.

National Research Initiatives & Results

Ice formation on wind turbine blades is a worldwide problem. Icing on turbine blades not only imperils the safety of the wind turbine itself, it also reduces power generation capacity. Goldwind resolved this problem by developing a new de-icing system, which includes an anti-icing coating, an icing security protection mode, and a blade heating system. This system should greatly increase wind power generation.

Information technology has monitored and controlled systems of wind turbines a well as manage wind farms. In 2017, many Chinese wind turbine manufacturers (e.g., Envision, Goldwind, Mingyang, etc.) launched new wind turbine monitoring and controlling systems. The new systems include more powerful functions, such as increasing power generation through precise control and supporting operation and maintenance through intelligent diagnosis and management.

To enhance the manufacturing efficiency and quality of wind turbines, some domestic manufacturers have begun to develop intelligent production lines. By using the technology of robotics, big data, and the "Internet of Things", wind turbines and components can be assembled automatically, and the management of the manufacturing process will become more efficient.

Figure 2. Natural frequencies and static tests of the longest blade (83.6 m)

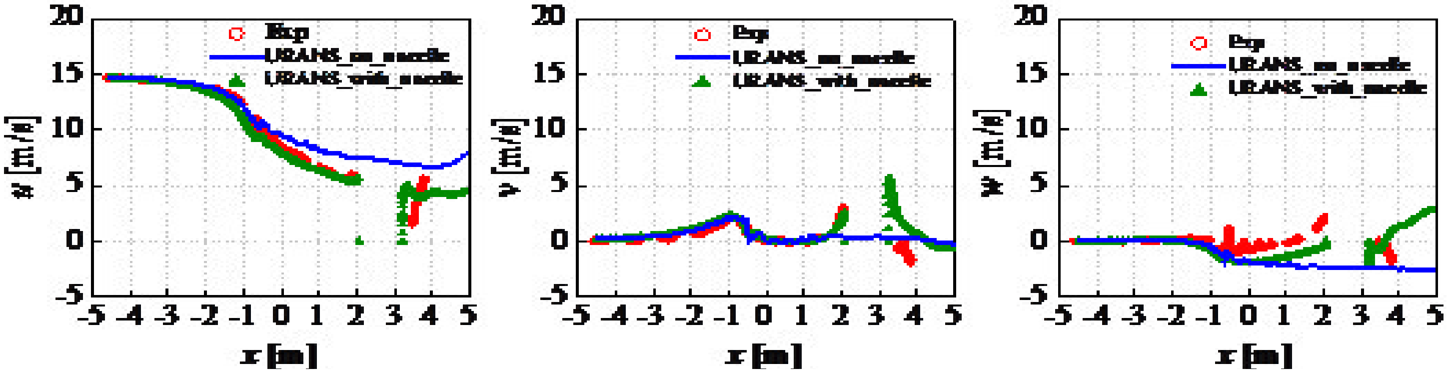

Figure 4. Comparisons of axial velocity distributions regarding nacelle effect

Test Facilities & Demonstration Projects

To improve development in low wind-speed areas, research on new wind turbine towers has drawn the attention of many manufacturers. In 2017, Envision, a famous wind turbine manufacturer in China, finished the construction of the highest wind turbine tower with a height of 140 m in Henan province.

The blade is the key wind turbine component for converting wind energy into mechanical energy. The length and quality of the blade determine whether the wind turbine can enhance production capacity and obtain a high power coefficient. Chinese blade manufacturers are striving to design longer and higher-quality blades. In 2017, SUNRUI, a domestic blade manufacturer, produced the longest turbine blade of 83.6 m.

The China General Certification Center, the predominant certification and testing body in China, finished the natural frequencies and static tests of the longest blade (83.6 m) in 2017 (Figure 2). This work showcases the advanced technical abilities of China's testing entity.

Collaborative Research

By the end of 2017, the 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 Benchmarking of Wind Farm Flow Models
- Task 32 Lidar Systems for Wind Energy Deployment
- Task 35 Full-Size Ground Testing for Wind Turbines and Their Components
- Task 36 Forecasting for Wind Energy
- Task 37 Systems Engineering
- Task 39 Quiet Wind Turbine Technologies

Wind power results in China include: a study on breakup and impingement characteristics of super cooled large droplets (Figure 3); the numerical simulation of turbulence characteristics and wind power output on a roof under different flow conditions; a comparative study of the aerodynamic performance of the New Mexico Rotor in yaw conditions (Figure 4); a dynamic calculation program and model comparisons of offshore wind energy; a study of large-scale wake flow field characteristics (Figure 5); optimization of wind turbine reliability data and evaluation index; a study on wind plant coding and revision of the relevant national standard.

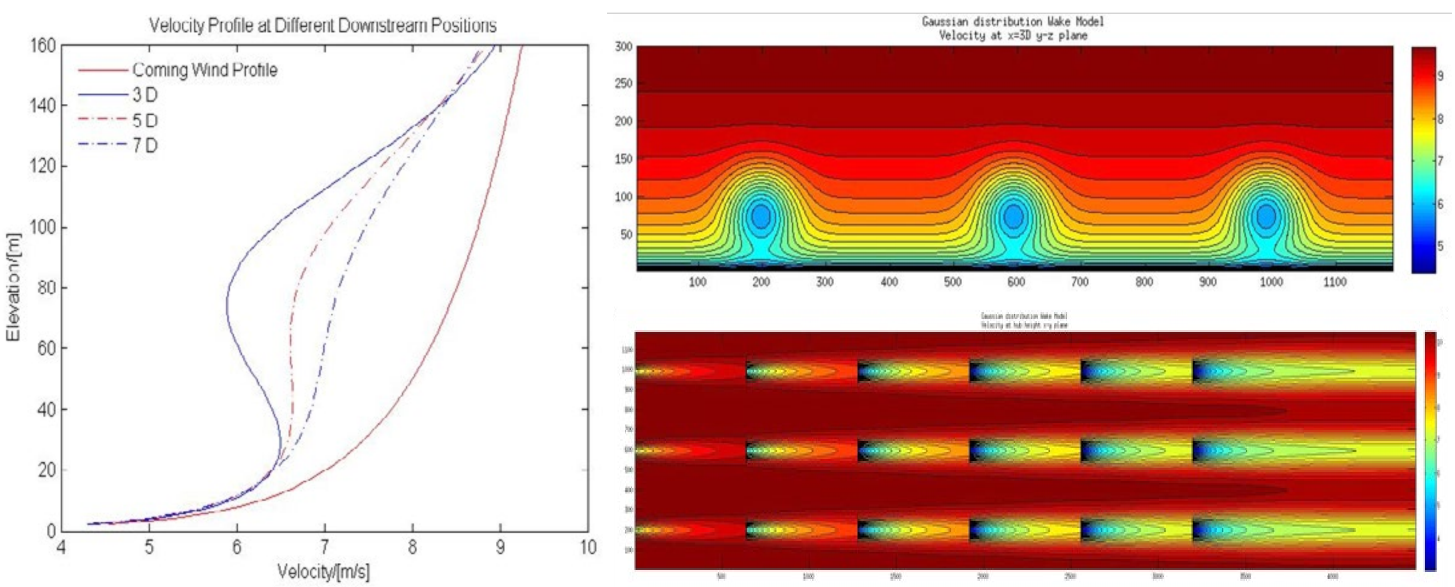

Figure 5. a) Wind velocity profile at different downstream position of the wind turbines; b) Wind velocity distribution, at x=3D, on Y-Z plane; c) Wind velocity distribution, on X-Y plane

Table 2. Top 10 Developers of New Wind Installations During 2017 (Source: CWEA)

#	Developer	Capacity (MW)	Share
1	China Energy Investment Corporation (China Guodian Corporation and Shenhua Group)	3,768	20.0%
2	Huaneng Group	1,901	10.1%
3	Datang Group	1,689	9.0%
4	SPIC	1,368	7.3%
5	Huadian Group	1,302	6.9%
6	CGN	1,175	6.2%
7	Huarun	668	3.5%
8	Tianrun	559	3.0%
9	Power Construction Corporation of China	525	2.8%
10	China Three Gorges Corporation	423	2.2%
	Others	5,461	29.0%
	Total	**18,839**	**100.00%**

Table 3. Top 10 Manufacturers of New Wind Installations During 2017 (Source: CWEA)

#	Manufacturer	Capacity (MW)	Share
1	Goldwind	5,230	26.6%
2	Envision	3,040	15.4%
3	Mingyang	2,460	12.5%
4	United Power	1,310	6.7%
5	CSIC Haizhuang	1,160	5.9%
6	Shanghai Electric	1,120	5.7%
7	XEMC-Wind	930	4.7%
8	Windey	830	4.2%
9	Dongfang Turbine	800	4.1%
10	Huachuang	730	3.7%
	Others	2,070	10.5 %
	Total	**19,660**	**100.00%**

IMPACT OF WIND ENERGY

Environmental Impact

According to the 13th Five-Year Plan, wind-generated electricity will reach 420 billion kWh, or 6% of the total electricity. This is very important for realizing the 15% target for non-fossil fuel energy in primary energy consumption.

In 2017, wind-generated electricity totaled 305.7 billion kWh, which saved about 109 million tons of standard coal per year, and reduced 277 million tons of CO_2, 0.95 million tons of SO_2, and 0.8 million tons of NO_x. Based on wind-generated electricity predictions for 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.

Economic Benefits & Industry Development

During the 13th Five-Year Plan period, new installation capacity will reach more than 80 GW, including more than 4 GW of new capacity of offshore wind-power. With land-based wind power investment of 7,800 CNY/kW (998.4 EUR/kW; 1,201 USD/kW) and offshore wind power investment of 16,000 CNY/kW (2,048 EUR/kW; 2,464 USD/kW), the total investment in wind energy during the plan period will reach more than 600 billion CNY (76.8 billion EUR; 92.4 billion USD).

The development of the wind energy industry will markedly enhance the development of related industries and increase employment. During the 13th Five-Year Plan period, about 15 jobs will be produced for every 1 MW of installed wind power capacity, and it is estimated that more than 800,000 people will be employed in the wind power industry through 2020. In 2017, more than 80 developers had new installations in China. The accumulated installed capacity of the top ten developers accounted for 71% of the total installed capacity (Table 2). The top five developers in China accounted for 53.3% of new wind installed capacity and the top ten developers accounted for 58.8% of new wind-power capacity.

Twenty-two manufacturers in China have new wind energy installations. The top manufacturer of new installations was Goldwind (5,230 MW), accounting for 26.6% of new wind installations, which greatly benefited the wind power industry. The top ten manufacturers accounted for 89.5% of the new wind installations in 2017 (Table 3).

In the past five years, market share has gradually concentrated in large companies. In 2017, the top five manufacturers' market share increased from 54.1% in 2013 to 67.1%, and the top ten manufacturers' market share increased from 77.8% in 2016 to 89.5%.

In 2017, many wind turbine manufacturers (including Goldwind, Envision, Mingyang, United Power, CSIC Haizhuang, and Shanghai Electric) released new products. Goldwind, Envision, and Mingyang released the 6-MW, 4.5-MW, and 5.5-MW offshore wind turbines, respectively.

NEXT TERM

In 2018, policies on the compulsory quota system and distributed wind power development will be issued in support of the development of the wind energy industry. In addition, new research projects will be carried out to improve product quality and enhance wind farm construction capacities. CWEA will continue to do its best to organize national research efforts and related activities.

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Opening photo: Wind farm in Jiangsu province (Photo credit: CWEA)

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

Denmark

Table 1. Key Statistics 2017, Denmark	
Total (net) installed wind power capacity	5.52 GW
Total offshore capacity	1.3 GW
New wind power capacity installed	0.37 GW
Decommissioned capacity (in 2017)	0.10 GW
Total electrical energy output from wind	14.8 TWh
Wind-generated electricity as percent of national electricity demand	43.4%
Average national capacity factor	32%
Target	50% renewable energy by 2030

OVERVIEW

Wind power capacity in Denmark increased by 275 MW in 2017, bringing the total to 5,521 MW (Table 1). The country installed 373 MW of new turbines—including 28 MW of new offshore wind (4 turbines)—and 98 MW were dismantled.

In 2017, 32% of Denmark's energy consumption came from renewable sources: 40% from oil, 15% from natural gas, 9% from coal, 2% from nonrenewable waste, and 2% from imported electricity. Wind-generated electricity met 43.4% of the domestic electricity supply (compared to 37.6% in 2016). The wind energy index was 102.3, compared to 90.2 in 2016. Recently, Denmark has focused on repowering land-based turbines, constructing four new large offshore wind farms, and developing new research test facilities.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

The Danish Government has an objective of 50% renewable energy by 2030. The existing agreement has been explained in earlier annual reports and can be found in the Danish Energy Agency's publication "Energy Policy in Denmark" (December 2012) [1].

In April 2017, the government-appointed Energy Commission presented its recommendations for a new energy policy to the Danish government. Denmark needs an ambitious, long-term energy policy as early as 2020, in order to reach the 2050 goal for a low-emissions society.

The commission considers the government's 2030 renewable energy target and the EU's CO_2 commitment as stepping stones along the road to 2050 [2]. The commission also provides important contributions to the preparation of the government's proposal for a new energy agreement. Parliamentary negotiations for the new agreement have been postponed from autumn of 2017 to 2018.

Progress & Operational Details

Figure 1 shows Denmark's wind-generated electricity production since 1977. The country added 275 MW of new wind power capacity in 2017, bringing the total to 5,521 MW, including small wind turbines. A total of 373 MW, comprised of 220 new turbines, were installed, while 98 MW (174 turbines) were dismantled (Figure 2).

Notably, 114 of the new turbines had a capacity at or below 25 kW. The largest rated turbine installed was an MHI Vestas 9.5-MW test turbine at the Østerild test site; unfortunately, this turbine had to be taken down after a fire in the hub. A detailed history of installed capacity and production in Denmark can be downloaded from the Danish Energy Agency website [3].

At the end of 2017, 6,157 turbines were operational, producing a total of 14.8 TWh—a new record for wind-generated electricity. The average capacity factor was 0.32 for those turbines, which have been in operation the whole year (average wind index 102.3). Beside the raising capacity, wind index fluctuations have influenced annual production. Over the last four years, the wind index has varied from 90.3 to 114.

Figure 1. Wind-generated electricity and share of electricity supply in Denmark

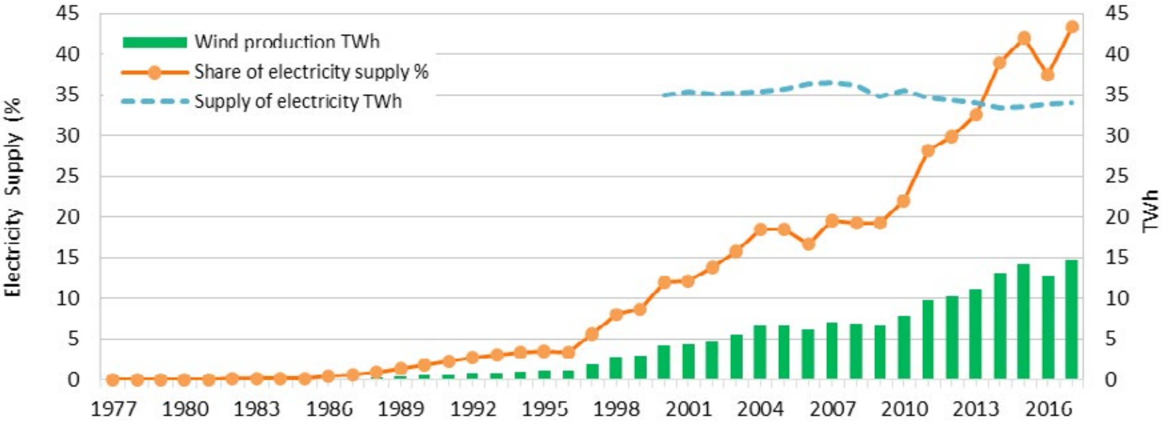
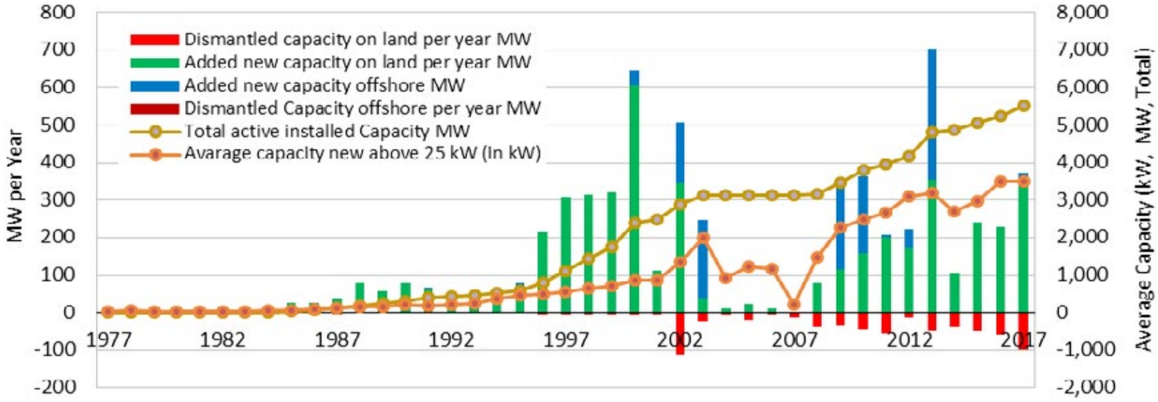


Figure 2. Added, dismantled, and total wind power capacity per year in Denmark



The 1,291 MW of offshore wind farms alone counted for 35% of Denmark's wind-generated electricity, (5.18 TWh) with an average capacity factor of 0.468. The average capacity of all installed turbines was 1,695 kW. The average capacity of the new turbines above 25 kW was 3,506 kW (Figure 2).

A 28-MW pilot offshore project in Nissum Broads, with four Siemens 7-MW turbines, was erected and put into operation at the end of 2017 [4].

Horns Rev III, with a capacity of 406.7 MW, will be constructed from 2017-2019 just North of Horns Rev II. The project will be using 49 MHI Vestas 164-8.3 MW turbines. The transformer platform, cables between the turbines, the sea cable to the shore, and transmission cable on land were completed during 2017, and all of 49 foundations were in place by the end of the year [5].

The 600-MW Kriegers Flak offshore wind farm will be constructed from 2018-2021. Here, developers have chosen to use 72 Siemens-Gamesa SWT-8.4 turbines. The wind farm is sited in the Baltic Sea between Denmark, Germany, and Sweden, near the future site of the German Baltic II offshore park. Energinet.dk and the German energy company Hertz 50 will be the first in the world to use offshore wind farm cables to connect power supplies between two countries [6].

Denmark has also continued planning for two nearshore wind farms: the 180-MV Vesterhav North and 170-MW Vesterhav South. Vattenfall has chosen the Siemens-Gamesa SWT-8.4 for both these projects [7].

Matters Affecting Growth & Work to Remove Barriers

In September 2017, the government signed an agreement that changes energy policy history in Denmark. For the first time, solar cells and wind turbines will compete to deliver the most green power to consumers.

There is a plan for two tender rounds in 2018 and 2019, with an approximate budget 800 million DKK (107 million EUR; 129 million USD). Support will be granted as a fixed price supplement on the electricity market price. Wind turbine projects already in the planning states will receive a transitional arrangement, and approximately 230 million DKK (31 million EUD; 37 million USD) will be allocated to support new test turbines.

It is expected that the tenders will result in approximately 140 MW of installed land-based wind and that approximately 125 MW of test turbines will also be installed. Up to 190 MW of land-based renewable energy can be accepted within the support system, depending on the bids, and approximately 130 MW of test turbines could be erected in the three-year support period.

Regarding offshore wind, Denmark, together with industry, has signed a declaration with Germany and Belgium that places greater emphasis on exploiting the potential of the North Sea for the construction of offshore wind farms.

Information on the status and progress of Danish offshore wind farms can be found on the Danish Energy Agency English website, including a new English publication on the Danish regulatory framework for offshore wind and the achieved results [8].

National R,D&D Priorities & Budget

The Danish Energy Agency administers the Energy Technology Development and Demonstration Program (EUDP) [9]. This R&D program was established by law in 2007 to support the development and demonstration of new technologies in the energy field. EUDP supports new technologies that can contribute to Denmark's energy and climate goals.

Since the creation of the program, more than 600 projects have been initiated with funding, for a total of 3 billion DKK (402 million EUR; 483 million USD). The partners behind the projects have matched EUDP funding with an equivalent amount. The former program, ForskEL (Energinet.dk), merged with EUDP in 2017. EUDP has published a new strategy for 2017-2019, which focuses on energy technologies for international markets in the coming years [12].

Priorities and funding are based on an analysis of the following three topics:

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

The Danish Energy Agency's ELFORSK program supports projects that ensures more efficient electricity use for consumers [10]. The Ministry of Education and Research's program, Innovation Fund Denmark, focuses on supporting more fundamental innovation [11].

An overview of these programs was published in a 2017 report entitled "Energy17" [13]. Figure 3 shows the development of total grant funding and the share to wind energy. Detailed information on funded projects, as well as developments of the granted funds over the last 10 years, can be found on the "Energiforskning" website [14, 15].

National Research Initiatives and Results

Megavind is Denmark's national partnership for wind energy, and the Danish equivalent of the European Technology and Innovation Platform on Wind Energy (ETIPWind). The partnership acts as catalyst and initiator of a strengthened strategic agenda for research, development and demonstration. Their latest report, *Annual Research and Innovation Agenda* (Nov 2017), provides specific priorities and recommendations for Danish funding programs [16].

DTU Wind Energy collaborated with LM Wind Power to develop a new method for observing how fatigue damages evolve in reinforced composite materials inside wind turbine blades [17]. The new technique makes it possible to identify how and where the damages begin and how they develop when composites are exposed throughout a turbine blade's lifetime.

New wind scanner developments have contributed to one of the most interesting research results in Denmark in recent years. Thanks to developments at DTU Wind Energy, Lidars have been used to measure wind 3-5 km in front of a wind farm, which hits the turbines 5-10 minutes later [18].

During 2017, the DTU Risø Campus tested a 4-Rotor Concept Turbine (so named because it has four rotors instead of the usual one) designed by Vestas. The 4-rotor Concept Turbine is part of research into whether wind energy can become more cost-competitive by delivering more wind-generated electricity while reducing the weight. Tests are carried out by Vestas, with researchers from DTU Wind Energy offering counselling and meteorological services [19].

Test Facilities & Demonstration Projects

Denmark has many 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 test field and Powerlab at DTU Risø Campus. Detailed information on the activities and test sites at DTU and LORC can be found at their websites [20, 21].

In March 2017, it was decided to expand the two wind turbine test centers at Høvsøre and Østerild with a total of four new test sites. These new sites will make it possible to test more advanced technology and higher turbines (up to 330 meters in Østerild and up 200 meters in Høvsøre).

Construction of the new Large-Scale Facility at DTU—part of the Villum Center for Advanced Structural and Material Testing (CASMaT)—was completed during 2017, and operations began at this facility in November [22].
A new wind tunnel, The Poul la Cour Wind Tunnel, is currently under construction at the DTU Risø Campus. The tunnel is financed by the Danish Agency for Science and Higher Education and Region Zealand and is expected to be operational in April 2018 [23].

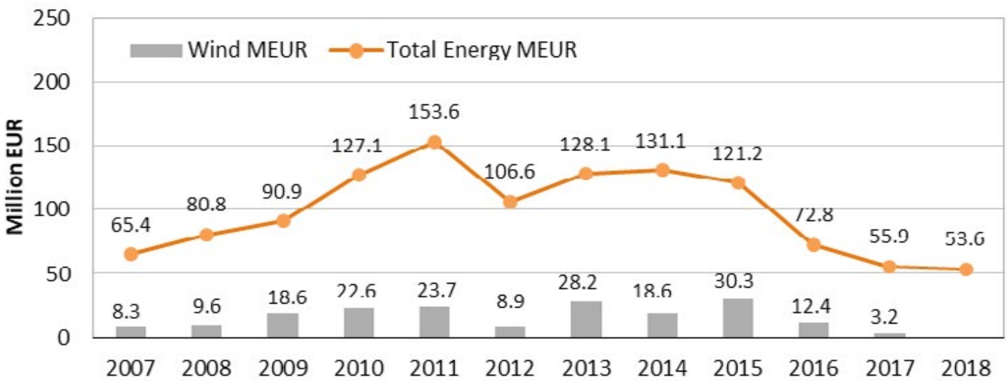


Figure 3. Energy R&D funding in Denmark (2018 is the budget for EUDP only with no specific allocated for wind)

Collaborative Research

Denmark utilizes public support to enable Danish companies, universities, and research institutions to take part in international co-operation. Denmark's work helps to promote R,D&D for energy technologies in TCPs under IEA, EU programs, and Nordic Energy Research programs.

IMPACT OF WIND ENERGY

Environmental Impact

Assuming that 1 kWh of wind-generated electricity substitutes 332 g of coal, the 14.8 TWh Denmark produced in 2017 would have resulted in the following reductions [24]:

- 11.4 million tons of CO_2 (772 g/kWh)
- 772 thousand tons of cinder and ash (52.3 g/kWh)
- 1,034 tons of SO_2 (0.07 g/kWh)
- 2,658 tons of NO_X (0.18 g/kWh)
- 295 tons of particles (0.02 g/kWh)

Economic Benefits & Industry Development

In 2016 the Danish wind industry achieved the highest turnover in seven years—close to the record levels in 2008 and 2009. Turnover rose 10.6%, from 14.2 billion EUR (17.0 billion USD) in 2015 to 15.7 billion EUR (18.8 billion USD) in 2016.

Exports rose 16% in 2016, reaching 7.4 billion DDK (1 billion EUR; 1.3 billion USD) and accounting for 4.1% of the total Danish exports. At the same time, employment grew 6.2%, from 31,251 employees in 2015 to 32,898 in 2016.

Newer data from 2017 can be found in Danish Wind Industry Association's report entitled *Branchestatistik 2017* (released June 2018) [25].

NEXT TERM

During the next three to four years, Vattenfall alone will add 1,350 MW of offshore wind capacity, with Horns Reef 3, Kriegers Falk, and the nearshore North Sea South and North Sea North. Denmark is also expecting an additional 150 MW of land-based wind. In a few years, wind turbines will supply the approximately 60% of Denmark's electricity consumption.

The Danish government is expected to present a proposal for a new Energy Agreement in 2018, which will replace the Energy Agreement from March 2012. Negotiations should have started in 2017, but were postponed to 2018.

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Opening photo: The La Cour Wind Tunnel (Courtesy of DTU Wind Energy)

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European Commission/ WindEurope

Table 1. Key Statistics 2017, EU	
Total (net) installed wind power capacity	168.7 GW
Total offshore capacity	15.8 GW
New wind power capacity installed	15.6 GW
Decommissioned capacity (in 2017)	0.6 GW
Total electrical energy output from wind	336 TWh
Wind-generated electricity as percent of national electricity demand	11.6%
Average national capacity factor	21.8% (land-based)
Target	20% RES by 2020

OVERVIEW

The Renewable Energy Directive is the main policy driver for wind energy in the European Union (EU) to 2020, and H2020 is the main instrument to support R&D at the EU level.

In 2017, the EU connected 15.6 GW of new wind energy capacity—an increase of 25% compared to 2016 (Figure 2). Of the new capacity, land-based installations accounted for 12.4 GW and offshore installations accounted for 3.2 GW. The total cumulative wind capacity grew 9.7% during the year, reaching 168.7 GW by the end of 2017. Wind power generated almost 336 TWh in 2017, covering 11.6% of the EU's electricity demand [1, 2].

Although the European Commission (EC) decreased its total funding specifically dedicated to wind energy R&D to 33 million EUR (40 million USD) in 2017, it increased its support for storage and the development of a flexible energy system, which is important for large scale wind energy penetration.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

The Renewable Energy Directive established the overall legal framework for the production and promotion of renewable energy sources (RES) [3]. It set a target of 20% share of renewable energy in final energy consumption by 2020. The legislation required all EU countries to adopt national renewable energy action plans (NREAPs), which include specific targets for wind energy.

Within the 28 EU member states, ten countries were above their general 2020 RES targets at the end of 2015. According to the EC energy model PRIMES, 16 other states are on track to reach their targets but will need to continue their current efforts to reach them by 2020. The remaining three EU member states—France, Luxembourg, and the Netherlands—must increase their action to meet their RES targets. 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 [4]. For many countries, 2017 was a transitional year as they moved toward new support schemes and tender mechanisms. A large number of projects were rushed to connect while feed-in-tariffs (FIT) still applied.

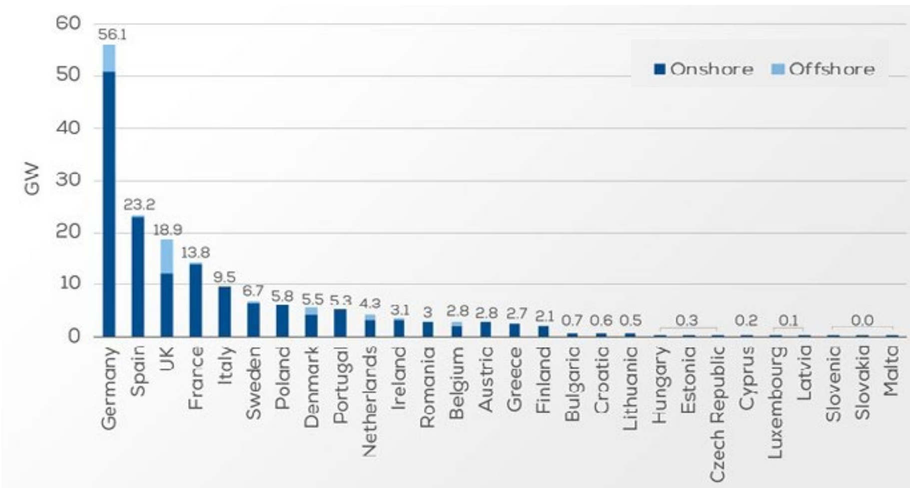


Figure 1. Cumulative installations land-based and offshore wind energy (Source: WindEurope)

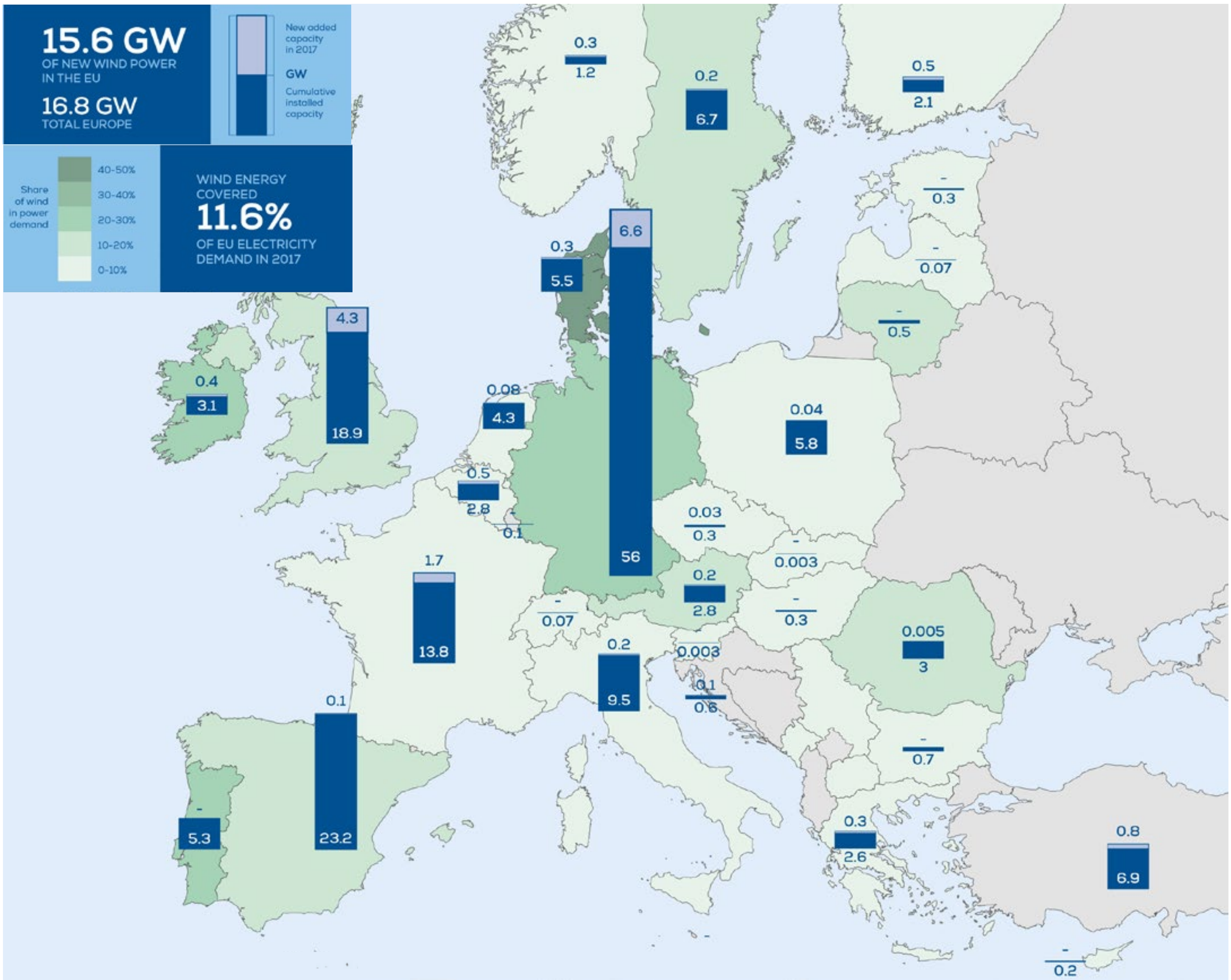


Figure 2. Gross and cumulative installed capacity in the EU in 2017 (Source: WindEurope)

While some projects continue accessing FiT (Belgium, France, and Germany) and Green Certificates persist in Sweden, Europe entered in an auction world in 2017. The first onshore wind tenders took place in France, Germany, and Spain. The U.K. ended its Renewable Obligation Certificates (ROCs).

Progress & Operational Details

During 2017, 15.6 GW of new wind power capacity was installed and grid-connected in the EU, 25% more than in 2016 (Figure 1). Land-based installations accounted for 12,484 MW, while offshore installations made up 3,154 MW. Cumulatively, 168.7 GW are now installed in the EU (a growth of 9.7% over 2016). By the end of 2017, the total installed wind power capacity in the EU was 79% of the 2020 target.

Germany is the EU country with the largest installed capacity (56.1 GW), followed by Spain (23.2 GW), the UK (18.9 GW), France (13.8 GW), and Italy (9.5 GW). Four other EU countries (Sweden, Poland, Denmark, and Portugal) have more than 5 GW installed. Seven additional EU countries have over 1 GW of installed capacity: the Netherlands, Ireland, Romania, Belgium, Austria, Greece, and Finland (Figure 1).

In 2017, wind-generated electricity met 11.6% of the EU-28's total electricity demand. Denmark achieved the highest penetration rate (44%), followed by Portugal (24%), and Ireland (24%). Ten out of the 28 member states had a wind penetration rate over 10% (Figure 3).

In 2017, the EU land-based wind capacity factor averaged 21.7%. Offshore capacity factor averaged 41.1%. The size and type of wind turbines installed in the EU in 2017 varied between member states. For example, the wind turbines in Denmark and Finland had an average power rating of 3.4 MW, while the turbines installed in Spain had an average rating below 2 MW. Regulatory restrictions on tip height, project duration, and wind regimes (low-speed or high-speed) account for some of the variation in wind turbine ratings in the different member states.

Offshore wind turbines in the UK and Germany had an average power rating of 6.0 and 5.6 MW, respectively. By contrast, all the turbines installed in Belgium use older turbine models (3.3 MW), as they belong to a project that started in 2009. In France, the relatively low rating (2 MW) is due to the type of project (demo floating wind turbine). In 2017, the world's first floating 30-MW wind farm, Hywind, started delivering electricity to the Scottish grid.

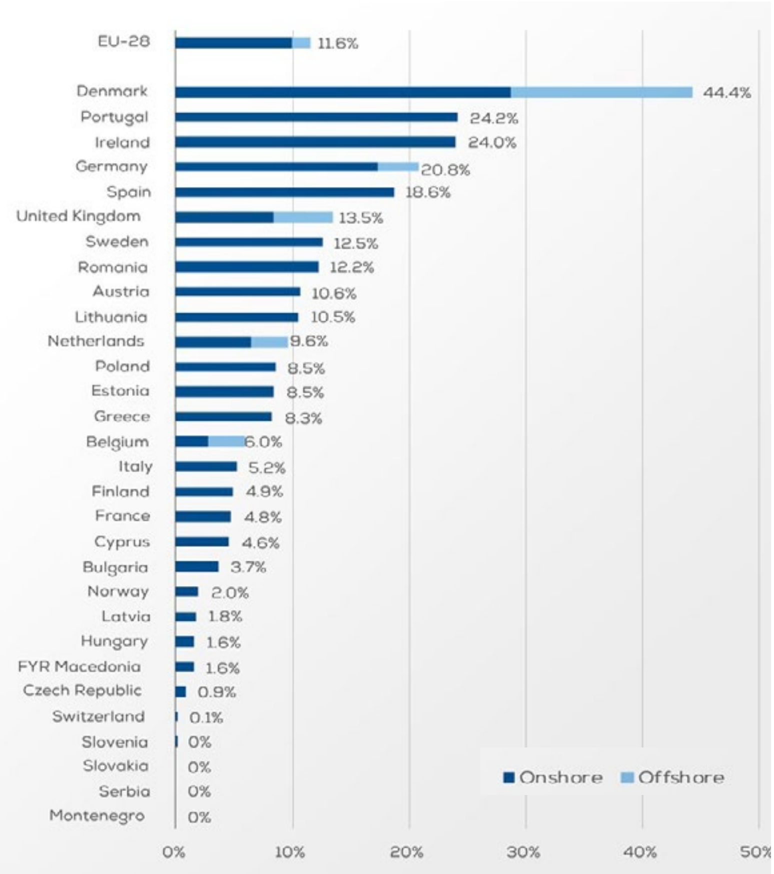


Figure 3. Wind power penetration rates in Europe (Source: WindEurope)

Matters Affecting Growth & Work to Remove Barriers

Long-term visibility and stable regulatory frameworks remain crucial for wind deployment beyond 2020. However, only eight member states have post-2020 renewable energy plans.

From an industry standpoint, other barriers to deployment include varying legislation between different European countries regarding spatial planning and the relatively slow rate of repowering—a result of asset life extension in mature markets. In some countries, such as France, Poland, Sweden, the UK, and the Baltic countries, regulations are tightening (e.g., set back distances, noise limitations, or wind turbine interference regulations for civil aviation and military radars).

Around 50% of the current cumulative installed capacity in the EU will reach the end of its operational life by 2030. The uptake of a repowering market will be determined by the implementation of fast-track administrative procedures. Finally, the rate of build out and reinforcement of the grid system to host the increasing wind energy capacity while minimizing curtailment (both land-based and offshore) is a crucial point for keeping a high pace of wind energy deployment in Europe.

R,D&D ACTIVITIES

National R,D&D Priorities & Budget

Horizon 2020 (H2020) is the main funding instrument for energy research and development at the EU level, with a budget of about 6.0 billion EUR (7.2 billion USD). In 2017, 17 projects started with total funding of about 28 million EUR (34 million USD) (Table 2).

The EU's R,D&D priorities include all aspects related to reducing wind energy costs, such as:

- New turbine materials and components
- Resource assessment
- Grid integration
- Offshore technology
- Logistics, assembly, testing, and installation
- Maintenance and condition-monitoring systems

Increasingly, the EU is supporting projects that focus on grid integration and energy storage projects, which will allow the energy system to accommodate higher shares of wind energy and other variable RES. The total EC funding from H2020 dedicated to wind-specific projects was about 25 million EUR (30 million USD) for projects starting in 2017. The average EC funding per wind energy project has remained relatively stable since 2009, with around 1.7 million EUR (2.0 million USD) per project.

Figure 4 shows how research and innovation (R&I) priorities have translated into actual projects since 2009 under H2020 and its predecessor FP7. The item "other" includes projects exploring emerging technologies such as kites or social acceptance.

Table 2. Wind Energy-Specific Funding Under H2020 for Projects Starting in 2017

H2020-Funded Projects	Total Project Cost million EUR (million USD)	EC Contribution million EUR (million USD)	Number of Projects
Wind-specific projects	34.89 (41.87)	25.13 (30.16)	13
Non-wind specific projects[1]	2.96 (3.55)	2.94 (3.53)	4
Total funding for wind energy	37.85 (45.42)	28.07 (33.69)	17

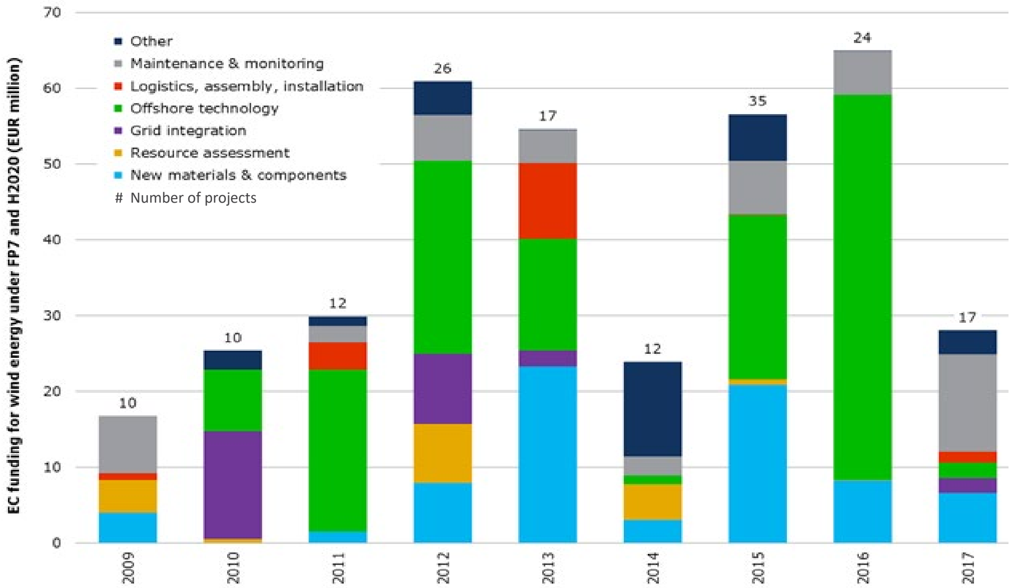
[1] Non-wind specific projects include projects on grid integration of renewables, projects developing materials for extreme conditions (cold climates, offshore applications), or projects developing common platforms/components (e.g., with wave/tidal energy)

National Research Initiatives & Results

Several FP7 funded projects were completed in 2017:

- **INNWIND.EU** (www.innwind.eu) was a project with 28 partners and a budget of nearly 20 million EUR (24 million USD). Its objectives included the conceptual design of beyond-state-of-the-art 10-20 MW offshore wind turbines and hardware demonstrations of their critical components.
- **The AVATAR project** (www.eera-avatar.eu) was about the development and validation of advanced aerodynamic models used in integral design codes for the next generation of large scale wind turbines (up to 20 MW).

Figure 4. Evolution of EC R&I funding under FP7 and H2020 for wind and number of projects, 2009-2017



- **LEANWIND** (www.leanwind.eu) provided cost reductions across the offshore wind farm lifecycle and supply chain through the application of lean principles and the development of state-of-the-art technologies and tools.

In 2017, many smaller H2020 projects, led by Small and Medium-sized Enterprises (SME), were also completed:

- **ELISA** focused on a full-scale prototype of a substructure system for offshore wind turbines.
- **EK200-AWESOME** developed an integrated 100-kW, container-based airborne wind energy (AWE) converter and storage solution.
- **ABLE (Air Blade Life Extension)** focused on a technology to extend the lifespan of a wind turbine blade.
- **IRWES (Integrated Roof Wind Energy System)** investigated a roof-mounted structure with a more efficient internal turbine than existing urban windmills.

Specific information on EU projects can be found in the CORDIS projects and results database [5].

Key EU-funded projects (non-SME) are as follows:

- **The ROMEO project** aims to develop and demonstrate an O&M information management platform, enabling improved decision-making processes to reduce O&M costs, improve reliability, and extend the lifetime of off-shore wind turbines and wind farms.
- **NEOHIRE** wants to reduce the use of rare earth elements cobalt and gallium in wind turbine generators by developing a new concept of bonded NdFeB magnets and new recycling techniques, using critical raw materials from current and future wastes.
- **WinWind** enhances the environmentally sound and socially inclusive wind energy market uptake by increasing social acceptance in 'wind energy scarce regions' (WESR).
- **SmartAnswer and InnoDC** are two projects under the Marie-Curie Innovation Training Network, respectively,1.) Smart mitigation of flow-induced acoustic radiation and transmission for reduced aircraft, surface transport, workplaces and wind energy noise; 2.) development of innovative tools for offshore wind and DC grids.

Test Facilities & Demonstration Projects

Of the 17 projects under the H2020 program that started in 2017, seven are funded under the Small and Medium-sized Enterprises (SME) instrument. In most cases, these projects received an EC contribution of 50,000 EUR (60,000 USD).

Collaborative Research

Projects funded by the EC foster international cooperation, and most require international collaboration between industry and research organizations. The Joint Research Centre of the European Commission has been and will continue to participate in the IEA Wind TCP Task 26 Cost of Wind Energy.

IMPACT OF WIND ENERGY

Economic Benefits & Industry Development

Europe invested a total of 22.3 billion EUR (26.8 billion USD) in wind energy in 2017—a 19% decrease from 2016. This is largely due to lower investments in offshore wind and cost reductions in both land-based and offshore wind CAPEX. There were 11.5 GW of new wind capacity financed in 2017. Wind energy investments accounted for 52% of new clean energy finance in 2017, compared to 85% in 2016. Offshore wind projects accounted for 35% of the investment activity in the renewable energy sector.

At the end of 2016 the wind energy industry accounted–both directly and indirectly–for about 260,000 jobs in the EU. It contributed 36.1 billion EUR (43.3 billion USD) to the EU's Gross Domestic Product, or 0.26% of the overall EU GDP [6]. The industry remains a global net exporter with a 2.4 billion EUR (2.9 billion USD) positive trade balance in products and services. This includes exports of 7.8 billion EUR (9.4 billion USD) and imports of 5.4 billion EUR (6.5 billion USD).

Over 80% of European wind energy companies have a commercial presence, including manufacturing sites outside of Europe in more than 80 countries. Five of the ten biggest wind turbine manufacturers in the world are EU-based.

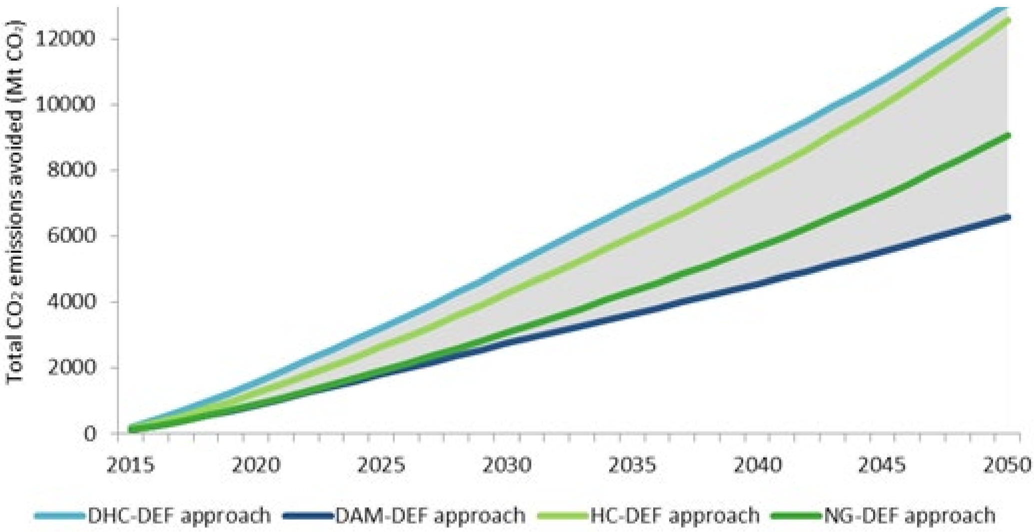


Figure 5. Total CO_2 emissions avoided by wind energy generation over the period 2015-2050 under different approaches Note: DHC-DEF (Dynamic high-carbon displacement emission factor), DAM-DEF (Dynamic all mix energy displacement emission factor), HC-DEF (High-carbon displacement emission factor), NG-DEF (Natural gas displacement emission factor)

Environmental Impact

The total CO_2 emissions avoided by wind energy in the European Union range from 6,600 to 13,100 Mt CO_2 over the period 2015-2050, representing around 5-10% of the cumulative emissions under the EU's reference scenario [7]. These values represent the upper and lower limits of wind energy's effect on the decarbonization of the European energy system.

Emissions are calculated based on two displacement factors. The first factor considers that wind energy will replace future high-carbon generation, providing an upper limit of potential avoided CO_2 emissions. The second factor considers that wind energy will displace high-carbon and other less-competitive renewable generation in the long run, resulting in a lower limit. These factors are dynamically computed on an annual basis, based on the evolution of the future energy mix.

NEXT TERM

The year 2018 will continue to be a transition year for the wind energy sector, as support schemes are changing. Land-based wind is expected to follow its current 12 GW/year level, but it may decrease from 2019 onwards. There is a strong pipeline of offshore projects, which should reach at least 24 GW of cumulative installed capacity by 2020.

The European Commission has proposed a recast Renewable Energy Directive together with a target of at least 27% renewables in the final energy consumption by 2030 [8]. The European Parliament reviewed this proposal in early 2018 and voted for a 35% renewables target. Over the next 12-18 months, member states, the European Parliament, and the European Commission will negotiate the target level and the adoption of the corresponding legislation.

The EC will continue to fund wind energy research and innovation via the Horizon 2020 program and financial instruments like the European Fund for Strategic Investments (EFSI) and InnovFin Energy Demo Projects (InnovFin EDP), implemented via the European Investment Bank.

To follow Horizon 2020 (2014-2020), in 2018 the Commission will propose Horizon Europe, a new Framework Programme for Research and Technology Development (FP9) for the 2021-2027 timeframe.

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Opening photo courtesy of Pixabay/Distel2610

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Finland

Table 1. Key Statistics 2017, Finland	
Total (net) installed wind power capacity	2.0 GW
Total offshore capacity	0.07 GW
New wind power capacity installed	0.516 GW
Decommissioned capacity (in 2017)	0.003 GW
Total electrical energy output from wind	4.8 TWh
Wind-generated electricity as percent of national electricity demand	5.6%
Average national capacity factor	32.5%
Target	No target

OVERVIEW

In 2017, Finland consumed 85.5 TWh of electricity with a peak demand of 14.3 GW. Carbon emissions from power generation in Finland totaled only 89 g CO_2/kWh—the lowest ever measured.

Wind power production broke the previous records and has now become the norm. At the end of 2017, installed wind power capacity amounted to 2,044 MW with 4.8 TWh of production. Renewables provided about 35.5% of the country's electricity consumption in 2017: 17.1% from hydropower, 12.8% from biomass, and 5.6% from wind power.

The National Energy and Climate Strategy for 2030 (published in 2016) introduced a tendering-based subsidy scheme, which fulfilled the new European Union (EU) guidelines for technology neutrality, was in preparation in 2017. Finland is aiming for 1.4 TWh of production capacity to be put out to tender between 2018-2020.

The 42-MW offshore demonstration wind farm, designed for and constructed in the demanding sea ice environment on the Finnish west coast, began operation in August.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

As part of the EU's 20% target, Finland's renewable energy source (RES) goal is 38% of the final energy consumption in 2020. The estimated share of RES in 2017 was 39%, exceeding the goal for 2020. 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).

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 (100.2 USD/ MWh) for 12 years. Producers are paid the guaranteed price, minus the three-month average spot price, as a premium every three months.

In 2016, the Finnish government published the National Energy and Climate Strategy for 2030 with the goal for 50% renewables in the energy end use. The government is currently planning a technology-neutral tendering process to acquire renewable-based generation, which is expected to launch in late 2018 [1].

The Ministry of Economic Affairs and Employment can also grant energy aid, which is increasingly targeted to new technology projects [2].

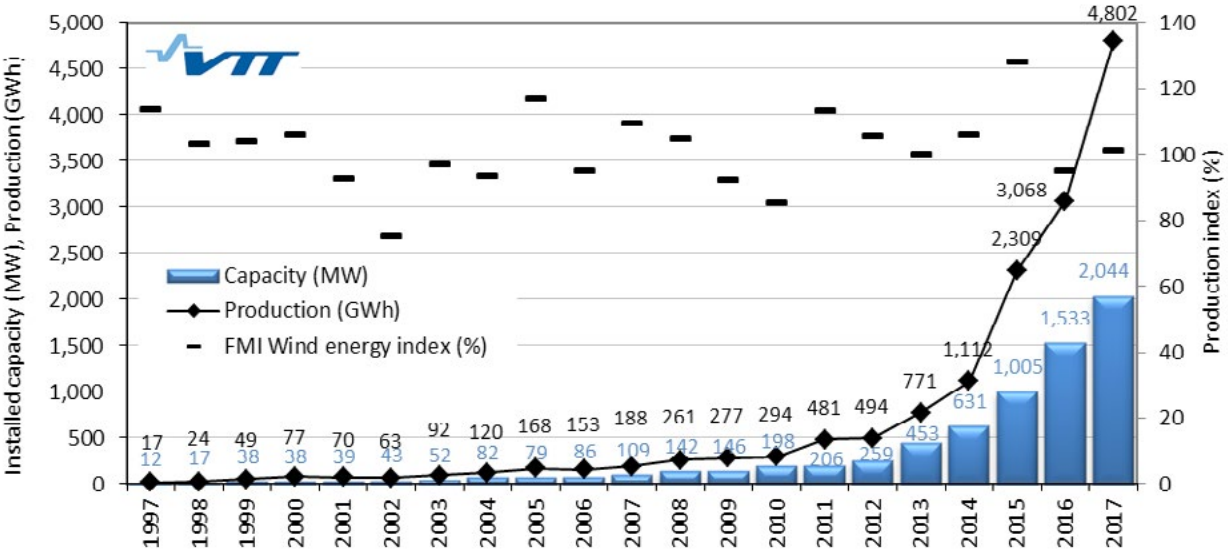
Progress & Operational Details

The feed-in tariff (FIT) system closed for new wind farms on 1 November 2017. The last wind farm was approved at the FIT system on 4 January 2018.The FIT-based system led to a market of 516 MW in 2017 (153 turbines). Three turbines with a total capacity of 3.4 MW were dismantled. The wind power capacity in operation reached 2044 MW.

Development toward larger turbines continued throughout 2017. The average turbine rating is now 2.9 MW for all turbines installed and 3.3 MW for the new turbines installed during the year. The largest single wind farm in operation has 34 turbines with 3.45 MW each and a total rated power of 117 MW, with expected annual energy output over 0.4 TWh/a.

Finland's total offshore capacity is 86.5 MW, including 44.3 MW built on caissons and 28.4 MW on small artificial islands.

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)



The 42-MW offshore demonstration wind farm in Pori on the Finnish west coast started operation in August 2017. Following a rush to secure sites for larger offshore wind power plants, interest to build has been low due to the improved economy of land-based turbines and lack of incentives offshore.

Wind-generated electricity increased by 55% in 2017 (from 3.1 TWh to 4.8 TWh)—80% of Finland's goal for 2020 and 5.6 % of the country's annual gross electricity consumption (Table 1, Figure 1). The weighted average capacity factor of wind farms operating throughout the year was about 32.5% (an increase from 27% in 2016). The production index for wind power averaged in 101% in 2017 (compared to 95% in 2016). Turbines in forested areas have high towers and larger rotors, and these designs provide considerably higher capacity factors than earlier turbine designs (Figure 2).

The average spot price in the electricity market Nordpool was 33 EUR/MWh (40 USD/MWh). This price is low, but it is a slight increase from the 32 EUR/MWh (38 USD/MWh) price in 2016.

Matters Affecting Growth & Work to Remove Barriers

Finland's main challenge in the future will be keeping the market going between the current renewables support system and the coming tender-based system, which was still in the planning stages. All developing projects are anxiously waiting for information regarding the next auction system.

The impact of wind farms on radar systems is preventing some projects in Finland, especially in the Southeast, Eastern and Northern parts of the country. The grid capacity is limiting new project development in some areas, where the project pipeline is large due to good wind conditions.

A government-financed study of the health and environmental effects of wind power was published in May 2017. The effects of low-frequency noise and infrasound on health are no longer a major issue in public debate, partly due to the results of the study. 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.

Public acceptance of wind power remains high. According to annual survey on energy attitudes, 75% of Finns support increasing wind production capacity.

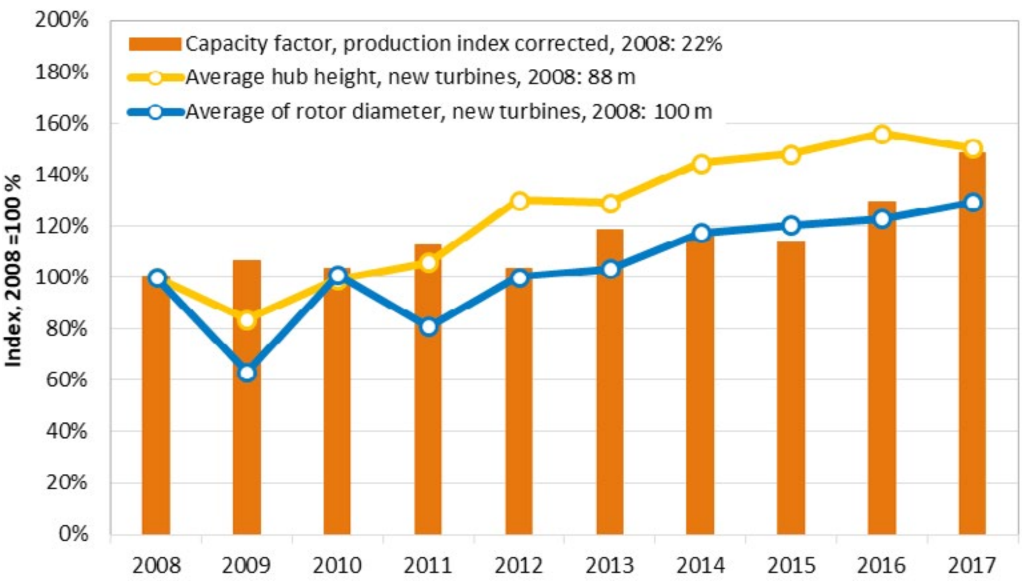


Figure 2. Growth of turbines built in each year and development of average capacity factor of all wind turbines in Finland, 2008-2017

National R,D&D Priorities & Budget

The Finnish Funding Agency for Technology and Innovation (Tekes) became BusinessFinland in January 2018, which is the main public funding organization for research, development, and innovation in the country, promoting competitiveness and international growth for Finnish companies. The focus is on assisting SMEs and supporting market-transforming solutions by large companies. BusinessFinland focuses on eight themes, and wind R&D projects fit into the following:

- Arctic: business activities from winter seafaring to digital services
- Digitalization: creating a competitive advantage as a global innovation and technology leader

Since 1999, Finland has not had a national research program for wind energy. Instead, Tekes/BusinessFinland funds individual industry-driven projects. The public funding level for wind power R&D projects in 2017 was around 1.2 million EUR (1.4 million USD) (Figure 3). Ongoing wind power-related R&D projects are mostly industrial development projects.

National Research Initiatives & Results

The Finnish Wind Power Research Network (FinWindResearch) is an ecosystem of wind power experts established in 2016 for 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, exchange information, and share and distribute latest research results via the FinWindResearch website. The network plans to host other events, such as web-based workshops, in the future.

The Health effects of sound produced by wind turbines project launched as a prerequisite to include wind power in the new auction-based premium tariff for renewables. The project concluded that there is a difference in the prevalence of annoyance between wind power areas, and that factors other than sound pressure level are associated with annoyance [3]. The effects of infrasound were studied, too, as some people who reside close to wind turbines have symptoms that they associate with infrasound from wind turbines. The report justified the need for additional research, as scientific studies on the effects of exposure to infrasound and audible noise from wind turbines are limited.

The Wind Turbine Sound Modeling and Measurement (windsome.uwasa.fi) project uses in-the-field observations of acoustics and wind turbine sound modeling methods in combination with a real-time subjective feedback system and background questionnaire. This unique combination of long-term sound measurements and real time subjective feedback is new; with the knowledge gained, it should be possible to model the wind turbine acoustics in different weather conditions and identify problematic conditions.

The EL-TRAN Consortium works to rethink the totality of the electric energy system under the energy transition. EL-TRAN published an updated potential assessment for wind power in Finland. It showed that the new low-specific rating turbines with high hub heights provide considerably higher technical potential: 100% of Finland's electricity demand can be met with wind power using best sites only (>47% capacity factor), compared to >40% capacity factor for 2002-2004 vintage turbines. New technology also reduces the uncertainty of land use restrictions. This assessment, including economic potential, will be published in *Nature Energy* in 2018.

The Neocarbon energy national project created visionary global 100% renewable energy scenarios (http://www.neocarbonenergy.fi/library/reports/). Wind energy has a strong role in the Northern hemisphere, but future cost reductions of solar PV, together with electric batteries, could mean that relatively little wind will be used in the solar belt.

Test Facilities & Demonstration Projects

VTT has operated an Icing Wind Tunnel facility for more than ten years. In 2017, VTT coordinated an industry consortium project to increase ice detector reliability and substantially reduce the time-to-market of new ice detector products. The project goal was to shift from the current slow, outdoor, full-scale "winter season" ice detectors testing to an accelerated, controlled, and repeatable laboratory "five winters in one week" testing at the VTT Icing Wind Tunnel (see Youtube video here) [4]. The novelty content of this project was high, and the results will benefit both industry and research community [5].

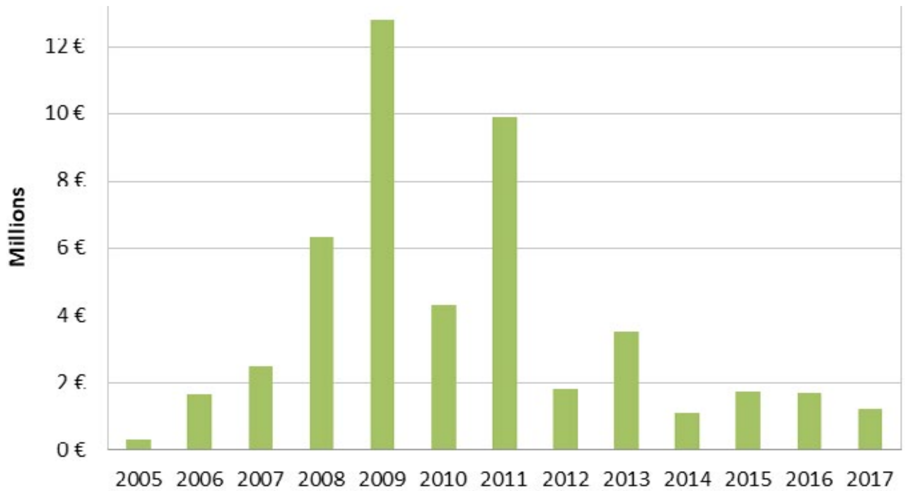


Figure 3. National R&D funding for wind energy related projects by Tekes (BusinessFinland as of January 2018); funding to research organizations represents usually 60% of the project budget

Collaborative Research

VTT is active in several EU, Nordic, and IEA research project frameworks. Within the IEA Wind TCP Finland takes part in:

- Task 11 Base Technology Information Exchange produces valuable information in identifying issues important for wind R&D in Finland
- Task 19 Wind Energy in Cold Climates (Operating agent VTT) brings results to developers in Finland. Task 19's Recommended Practices report sub-chapter on ice throw helps the work of the Finnish Wind Power Association (FWPA) in preparing safety guidelines.
- Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power (Operating agent VTT) is linked to research projects VaGe, EL-TRAN and NeoCarbon.
- In 2017, Finland gave up the membership in Task 31 WAKEBENCH: Benchmarking of Wind Farm Flow Models.
- Task 36 Forecasting for Wind Energy (Vaisala, VTT, and FMI) is linked to national project VaGe.
- Task 28 membership was renewed in 2017, as Acordi, supported by Energy Industries and FWPA, are gathering the inputs from Finland to this international collaboration.

IMPACT OF WIND ENERGY

Environmental Impact

Given the structure of electricity generation in Finland, the initial effects of wind power on greenhouse gas emissions would be about 700 g CO_2/kWh. Thus, wind power production saved up to 3.4 million tons of CO_2 in 2017. This reduction of CO_2 helped bring the emissions of all power generation in Finland down to 89 g/kWh in 2017 (103 g/CO_2/kWh in 2016).

According to a study by Sweco Environment Ltd, approximately 4,200 people will be employed in wind power planning, construction, and O&M by 2020. 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.

Economic Benefits & Industry Development

Locally, the municipality receives property tax revenue wind power. Depending on the power plant value and the municipal tax rate, the annual real estate tax of 3-MW wind turbines is 6,000-11,500 EUR/yr (7,200-13,800 UDS/yr). This is significant additional income for some small municipalities. The real estate tax that one wind power plant generates for the municipality during its life cycle, depending on the investment cost and the real estate tax rate, is approximately 100,000-200,000 EUR (120,000-240,000 USD).

Finland's technology sector is employing 2,000-3,000 people. Development and Operation and Maintenance (O&M) has led to an increase in direct and indirect employment, with 2,200 jobs in 2015. This figure will decrease in 2018, as wind farm development has slowed or stopped due to the FIT system closure prior to the coming auction-based support scheme.

There are more than 100 companies in the whole value chain, from development and design to O&M and other service providers, with the majority of wind farm planning and construction happening domestically.

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.

Finland produces many materials for 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. Peikko offers foundation technologies based on modular components.

A growing number of companies offer O&M 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.

NEXT TERM

Following the strategy, the technology-neutral tendering process to acquire renewable-based generation capacity will start in late 2018. The government limited the tendering scheme to 1.4 TWh of cost-effective electricity production from renewable energy (originally 2 TWh) and rolled the tendering in a single round instead of the original plan of two phases. The approved projects will receive a feed-in tariff. The Energy Authority is preparing the details of the tendering process, which is subject to final approval by the government.

Because of these circumstances, less new capacity is expected to be constructed in 2018 compared to 2017. Some of the developed projects have applied for a special investment grant for renewable technology projects with new technology innovation, but with no success.

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Opening photo: Kayaking in the Pori offshore wind farm (Source: Hannele Holttinen)

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

France

Table 1. Key Statistics 2017, France	
Total (net) installed wind power capacity	13.5 GW
Total offshore capacity	0 GW
New wind power capacity installed	1.6 GW
Decommissioned capacity (in 2017)	---
Total electrical energy output from wind	22.6 TWh
Wind-generated electricity as percent of national electricity demand	8.4%
Average national capacity factor	21.8% (estimate)
Target	2018 wind power capacity: 15 GW land-based; 0.5 GW fixed offshore

OVERVIEW

Wind power is an increasingly significant source of renewable electricity production in France, accounting for nearly 28% of all installed renewable power capacity. France set a new record for wind power industry development in 2017, with over 1.6 GW of newly installed wind power capacity. These installations bring the country's total land-based installed wind power capacity to approximately 13.5 GW.

The record installation rates are the continued result of simplified administrative procedures and better visibility in terms of regulatory changes. The annual electrical energy output from wind was 22.6 TWh, a significant increase from 2016. This increase is the result of higher installed power capacity, with an unchanged capacity factor with respect to the year before. Wind and all renewables covered 4.7% and 18.4% of national electricity demand, respectively.

The first call for tender of 500 MW of onshore wind power and some initiatives to facilitate wind deployment also occurred in 2017. Concerning offshore wind, the first phase of a competitive dialogue for a third tender in the Dunkerque area took place, as well as preparation of a new tender in the Oléron area. The start of studies for a commercial call for tenders for floating wind farms was also announced in 2017, following the ongoing wind farm pilot projects.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

Along with the Paris Agreement during COP21, 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.

The Pluriannual Energy Program (Programmation Pluriannuelle de l'Energie, PPE) was updated during 2015 and 2016 to set renewable energy targets for 2018 and 2023. 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

Additionally, the following targets are set for the end of 2023:

- 21.8-26 GW land-based wind power capacity
- 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 power capacity, with between 200-2,000 MW of ongoing projects, depending on the outcome of the first pilot farm projects and price levels
- The PPE is currently being revised and submitted to a public debate that will run up to 2018 and will define new objectives for the periods to come.

Progress & Operational Details

During 2017, France broke its 2016 record by connecting over 1,650 MW of new wind-power capacity, leading to a total of 13.5 GW of installed capacity. With a capacity factor almost equal to 2016, wind-generated electricity production increased 13% since 2016, totaling 22.6 TWh. The percentage of electricity demand met by wind energy increased to 4.7%. Should this high installation rate continue, the target set by the PPE will be reached by the end of 2018. The installation rate should, however, further increase to meet the 2023 target.

Offshore projects are making progress with the third call for tender for the area offshore of Dunkerque following a competitive dialogue phase. A call for tender is being prepared for the area offshore of Oléron for fixed wind, while some studies have been launched to identify locations for commercial floating wind farms.

Annual wind-generated electricity production increased in 2017 as the result of a very active year for installations. The average capacity factor is estimated at 21.8%, 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 (65-130 USD/MWh), but can decrease to 50-94 EUR/MWh (60-113 USD/ MWh) [1].

Matters Affecting Growth & Work to Remove Barriers

The Energy Transition for Green Growth Act confirmed in 2015 an already ongoing trend toward simplification of the permitting and licensing process. During 2017, several measures were adopted, including:

- Application of a single environmental authorization process to the whole territory ("one stop shop" approach)
- The reduction of deadlines for appeals within this single authorization process
- The implementation of incentives for residents to acquire shareholdings in limited companies involved in local renewable energy projects
- The full application of the "Complément de remuneration" funding mechanism

The creation of a work group at the Ministry level also led to several propositions, including the following important measures:

- The suppression of one level of jurisdiction regulating litigations
- The revision of the IFER tax (imposition forfaitaire pour les entreprises de réseaux) to redistribute this tax more locally

The first tender for 500 MW of onshore wind-power installations took place in 2017. Five new 500-MW tenders are expected to be launched through May 2020.

Finally, the so-called "Hydrocarbon" law included some measures for the development of offshore wind, including the obligation for RTE (French TSO) to build connections to the grid for offshore projects.

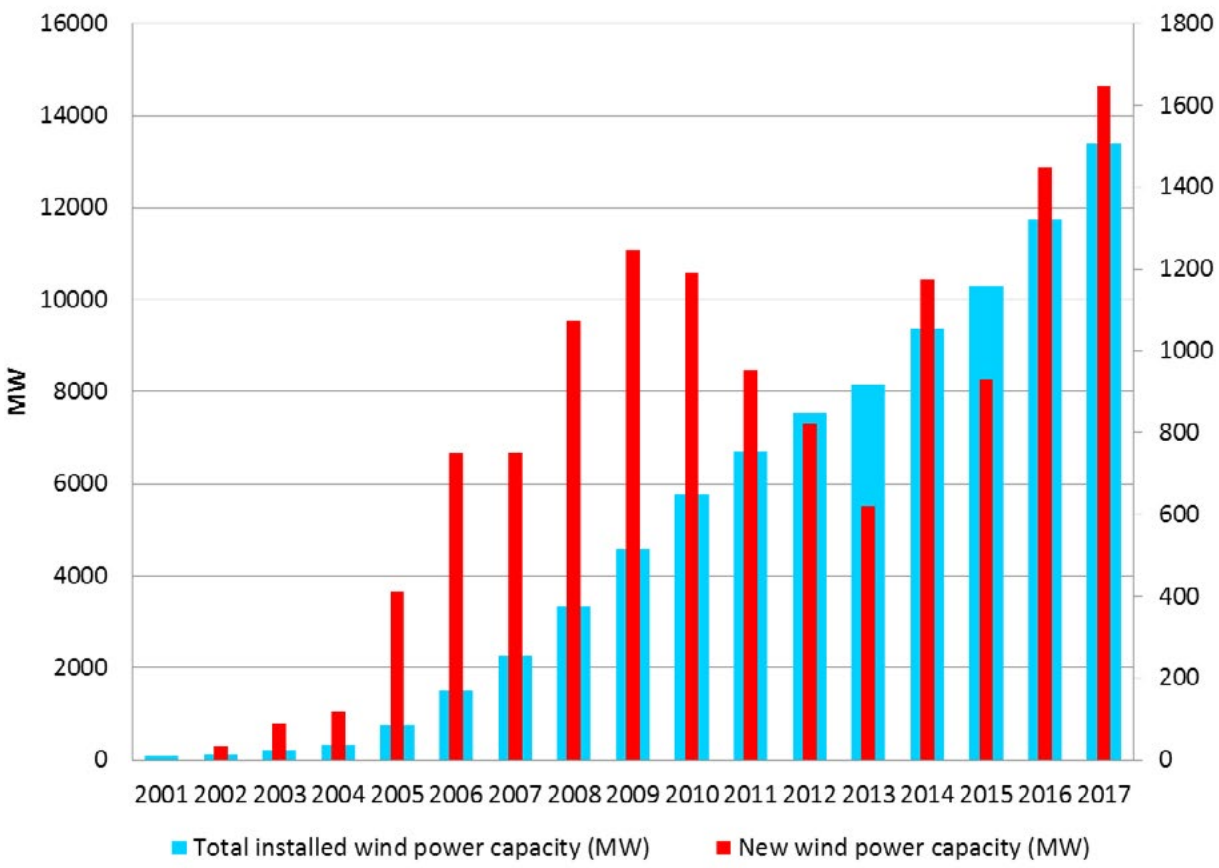

Figure 1. New and total wind power capacity in France (2001-2017) [2]

R,D&D ACTIVITIES

National R,D&D Priorities & Budget

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 this area. ADEME funds and administers three kinds of projects: PhD theses; R&D projects for intermediate technology readiness levels (TRL); and the Programme des Investissements d'Avenir, which is 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. A dedicated call for tender for floating wind farm pilot projects highlighted the focus on floating wind.

Even though no national statistics are emitted on the R&D budget, 2017 remains a very active year, with the support to the four floating-wind pilot farm projects.

National Research Initiatives & Results

The DGE (drone générateur éolien) project was launched with the support of ADEME. Led by the start-up BladeTips Energy, the project aims to develop an airborne wind energy device and has already produced several small-size prototypes. As a first step, it targets a 20-kW power system.

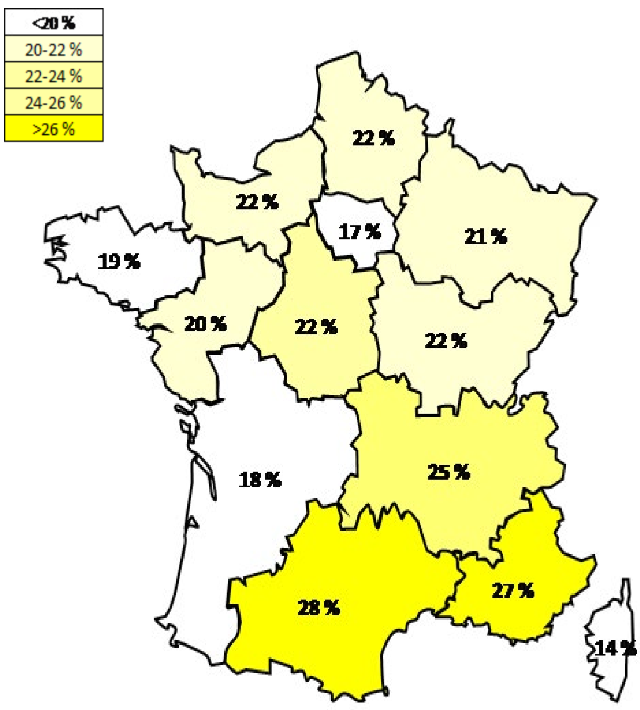

Figure 2. Capacity factors by region in France during 2017 [4]

The Helice project, led by Leosphere and supported by ADEME, aims to develop a new lidar technology to specifically address the control market with drastically reduced costs.

The ePenon project, also supported by ADEME and led by the Mer Agitée Company, develops dedicated wind speed sensors that can be installed in the tips of wind turbines to better control them based on real-time measurements.

Test Facilities & Demonstration Projects

The four pilot projects awarded in 2016 for floating wind farms have progressed on permitting and engineering work. These projects are targeting installation in 2020 and 2021 and include 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-Ile 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 Eoliennes Flottantes du Golfe du Lion project**, led by Engie, Caisse des depots, 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

In 2017, a 2-MW demonstrator was inaugurated and tested along the quay of Saint-Nazaire. The installation, hook-up, and commissioning will be finalized in 2018. This will be the first offshore wind turbine installed in France.

Collaborative Research

Since joining IEA Wind TCP in 2014, nearly 15 French organizations, including private companies, Regional Transmission Organizations (RTOs), Small to Medium Enterprises (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
- Task 30 Offshore Code Comparison Collaboration, Continued, with Correlation (OC5)
- Task 31 WAKEBENCH: Benchmarking of Wind Farm Flow Models
- Task 32 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.

IMPACT OF WIND ENERGY

Environmental Impact

Wind energy provided approximately 28% of the overall installed renewable power capacity in France, which amounted to 48.7 GW at the end of 2017. This constituted the second largest source after hydroelectricity. In terms of electricity production, wind contributed to 25% of the total renewable energy production.

Economic Benefits & Industry Development

Wind energy provided 10,000-11,000 full time equivalent 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 national wind turbine manufacturer in France, several players such as DDIS, Vergnet, and, more recently, Poma Leitwind, contribute to the French economy. The wind industry in France also includes facilities from several large wind turbine suppliers such as GE, Siemens/Gamesa, and an LM Windpower blade factory that is being installed.

A variety of suppliers already exist, such as STX for offshore foundations, Nexans for the electric cables, Leroy-Somer for generators, and Rollix for blade and yaw bearings. Several SMEs are also providing advanced technologies; for example, LeoSphere 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 (2.2 billion USD). Of this total, 1.3 billion EUR (1.6 billion USD) are devoted to investment in new parks, and 5.0 million EUR (6.0 million USD) are intended for the operation and maintenance of existing wind turbines

NEXT TERM

In 2018, the new revision of the PPE should be finalized and set new targets for wind power capacities. Several of the aforementioned measures aiming at facilitating the installation of wind turbines should become operational in the coming term.

Finally, the SmartEole project—focusing on wind turbine control at blade, turbine, and farm levels—will be finalized and results will be presented during a dedicated international workshop.

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Opening photo: Coyecques wind park, France (Photo credit to Maia Eolis-Engie Green)

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Author: Daniel Averbuch, IFPEN Energies nouvelles, France.

Germany

Table 1. Key Statistics 2017, Germany	
Total (net) installed wind power capacity	55.8 GW
Total offshore capacity	5.41 GW
New wind power capacity installed	6.76 GW
Decommissioned capacity (in 2017)	0.47 GW
Total electrical energy output from wind	106.61 TWh
Wind-generated electricity as percent of national electricity demand	17.7%
Average national capacity factor	23.2% (estimate)
National wind energy R&D budget	95.97 mil EUR; 101.1 mil USD
Target	At least 80% RES in electricity consumption by 2050; 40-45% by 2025; 55-60% by 2035

OVERVIEW

Renewable energy met 36.2% of Germany's national electricity demand in 2017. Wind-generated electricity produced the largest share of this energy, at nearly 49%.

Germany has 29,844 wind turbines, which account for nearly 56 GW of installed wind power capacity. In 2017, new installed wind power capacity was 6,759 MW, compared to 4,993 MW in 2016. New wind power capacity reached an all-time high, proving that the German Energy Transition is well underway.

Due to better wind resources in 2017, Germany's wind sector produced 106.6 TWh of wind-generated electricity, compared to 79.9 TWh in 2016. Ongoing auctions took place with regard to the Renewable Energy Act (EEG 2017) and led to reduced bid prices for land-based wind energy and even up to zero bid strike prices offshore.

Germany pursues a broad R&D program on renewable energies and energy efficiency. Efforts for wind energy R&D include larger wind turbine components (like rotor blades and drive trains) that take into account land-based logistics requirements and offshore demands for substructures. Digitization within turbine control, reliable wind turbine performances, and the forecasting of site-specific wind resources play an important role for R&D projects, along with the constitution and expansion of test facilities and the holistic consideration of social acceptance [1-4, 7, 8].

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

There have been no changes in the targets since 2016, when 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 to 2019 and 2.9 GW/yr after 2020.

Offshore wind power capacity is expected to reach 15 GW by 2030 (0.5 GW/yr in 2021 and 2022, and 0.7 GW/yr from 2023-2025). Land-based pilot R&D turbines with a power capacity of up to 125 MW/yr are exempted from the obligatory call for bids within the EEG 2017. Those wind energy capacities will contribute to the overall goal of providing 55% to 60% renewable electricity by 2035 and at least 80% by 2050 [9, 10, 15].

Progress & Operational Details

The past year was exceptional for overall renewable electricity generation, and wind energy generation in particular. Electricity provided by land-based wind power reached 88.7 TWh (up from 67.7 TWh in 2016), an all-time high; this strongly contributed to achieving a 36.2% (up from 31.6% in 2016) share of renewable electricity generation in 2017 [1-4].

There is a significant difference in the possible annual wind energy production from 2016 to 2017. Using the wind data from the years with best (2007) and worst (2010) wind conditions gives a possible production range for 2017 installed land-based wind energy of 70 TWh to 91 TWh [4].

Offshore wind energy also increased in 2017; 1,275 MW of wind generation capacity were commissioned in 2017 (compared to 849 MW in 2016), bringing offshore wind energy capacity to 5,407 MW (4,132 MW in 2016). This led to a total 17.9 TWh of offshore wind-generated electricity, more than 46% compared to the previous year (12.3 TWh in 2016). In total, wind energy contributed 106.6 TWh (79.9 TWh in

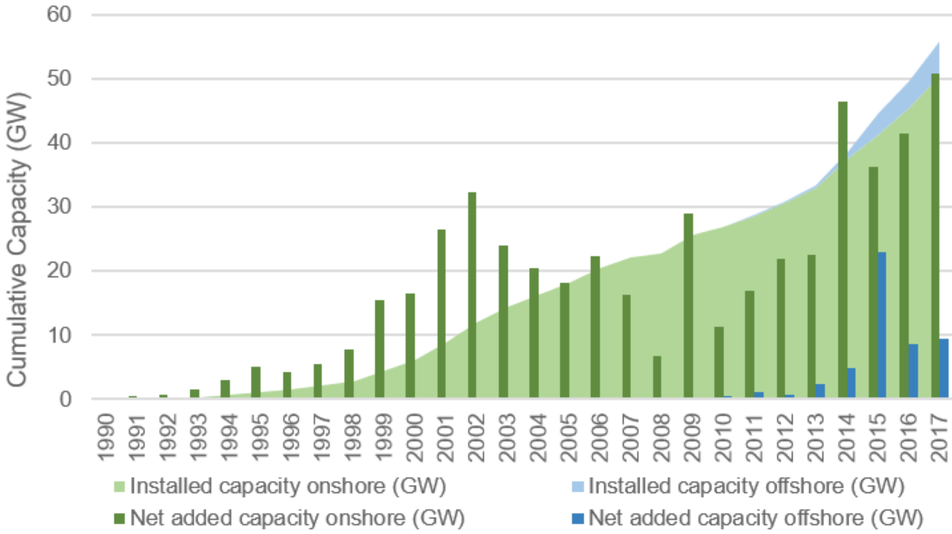

Figure 1. Development of installed/ net added wind power capacity land-based and offshore Germany 1991-2017 (Source: Federal Ministry for Economic Affairs and Energy BMWi, Layout: IEA Wind TCP)

2016) to overall renewable electricity generation [1, 4]. The average size of new land-based wind turbines is 2,976 kW (up from 2,552 kW in 2016), with an average rotor diameter of 113 m (up from 109 m in 2016). Compared to the previous year, the average hub height remains at 128 m. Average specific wind power capacity has now decreased to 309 W/m², down 5 W/m² since 2016 [3].

Offshore, the average size of new wind turbines is now 5,644 kW (5,244 kW in 2016), with an average rotor diameter of 138 m (145 m in 2016) and hub height of 96 m (104 m in 2016). Unlike land-based wind energy, offshore wind energy is increasing its average specific capacity (up to 387 W/m² from 314 W/m² in 2016) [2].

Several new wind turbines were announced or installed as prototypes in 2017. Aurich-based manufacturer Enercon has installed a prototype of its E-103 EP2 in the region of Burgundy, France [17]. In North Rhine-Westphalia, Enercon installed a hybrid tower version of its E-141 EP4 portfolio; with a hub height of 159 m, it is their highest tower yet [17]. The company is also developing two new versions of the EP3 platform—E-126 EP3 for wind class IIa sites and E-138 EP3 for wind class IIIa sites. The more compact design will differ from Enercon's iconic egg-shaped nacelle [18].

Nordex announced new versions of wind energy converters in 2017. The light-wind N131/3900 shows an 8% improvement over the N131/3600. Nordex also announced the light-wind wind energy converter N149/4.0-4.5, with a 30% increase in rotor sweep and a variable power output of 4 to 4.5 MW [19].

Siemens Gamesa Renewable Energies (SGRE) introduced the SG 8.0-167 DD. Its 82 m long blades increase the direct drive wind turbine's rotor-swept area by 18% compared to its predecessor, SWT-7.0-154. SGRE also launched a new geared turbine (SG 4.2-145) within its new 4.X platform [20].

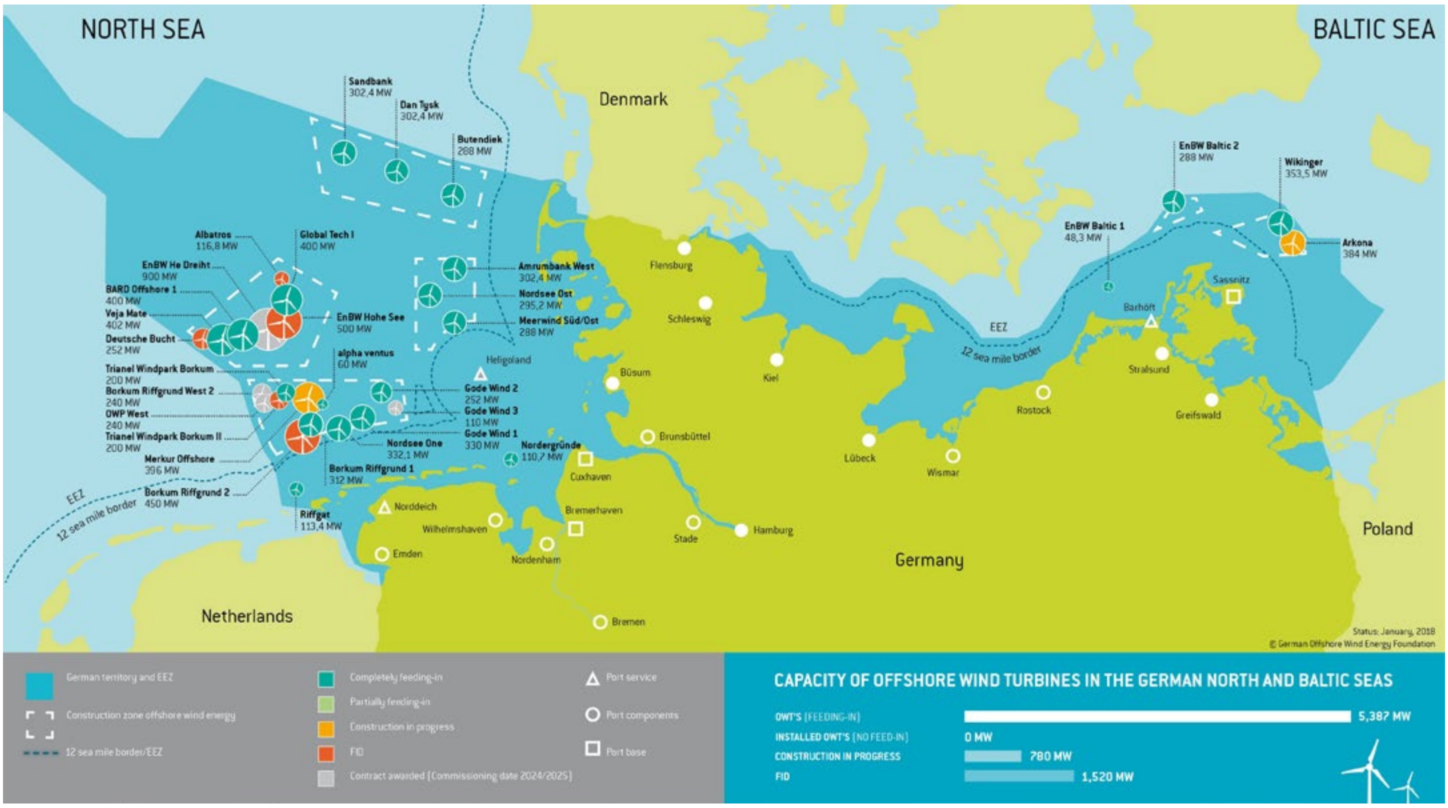

Figure 2. Power capacity of offshore wind turbines in the German North and Baltic Seas (Source: Stiftung OFFSHORE-WINDENERGIE)

The average investment costs in 2017 for land-based and offshore wind power were 1,416.85 EUR/kW; 1,700.0 USD/kW (1,450.14 EUR/kW; 1,740.0 USD/kW in 2016) and 2,541.18 EUR/kW; 3,049.0 USD/kW (3,871.80 EUR/kW; 4,647 USD/kW in 2016) respectively—clearly showing the trend in cost reductions. Compared to 2016, the O&M costs for land-based wind power stayed at a stable 41.4 EUR/kW (49.7 USD/kW, while offshore O&M was reduced by 7% to 77.7 EUR/kW (93.2 USD/kW) (Table 2) [1].

Siemens Gamesa Renewable Energy was created in April 2017, with the merger of Gamesa Corporación Tecnológica and Siemens Wind Power. The legal domicile and global headquarters of the merged company will be located in Spain. The onshore offices will be also in Spain, while the offshore headquarters will be located in Hamburg, Germany, and Vejle, Denmark [21].

Matters Affecting Growth & Work to Remove Barriers

The new auctioning system in Germany has decreased the price for land-based wind energy significantly. Within the three rounds in 2017, the average price dropped from 57.1 EUR/MWh to 42.8 EUR/MWh to 38.2 EUR/MWh (68.5 USD/MWh to 51.4 USD/MWh to 45.8USD/MWh. However, the auctions allowed community projects to bid without a permit and gave them longer lead time to build the project.

Table 2. Development of O&M Costs

		2016	2017	Percent Change
O&M Total Cost (million EUR)	Land-based	1,880	2,090	
	Offshore	350	420	
Wind Power Capacity (MW)	Land-based	45,454	50,469	
	Offshore	4,132	54.07	
O&M Cost (EUR/KW)	Land-based	41.4	41.4	0.0%
	Offshore	84.7	77.7	-7.0%

This resulted in a situation, where more than 90% of all auctioned capacities have been won by citizens' projects. It is therefore uncertain to what extent those projects will be built [7, 22].

Similar to other European tenders, German offshore auctions in 2017 led to low average prices of 4.4 EUR/MWh (5.3 USD/MWh), with highest bids of 60.0 EUR/MWh (72.0 USD/MWh) and lowest bids as low as a zero strike price [23]. Nevertheless, it is important to note that offshore grid connection is provided by Transmission System Operators in Germany.

R,D&D ACTIVITIES

National R,D&D Priorities & Budget

Germany pursues a broad R&D program, rather than focusing on a specific subject. Larger turbines and components—like rotor blades and drive trains—come with larger challenges, including materials and onshore logistics, as well as offshore substructures and foundations. Test facilities also play an important role in the German R&D landscape. Digitization within turbine and wind-farm control, reliable wind turbine performance, and the forecasting of site-specific wind resources were topics of R&D projects in 2017, along with holistic considerations of social acceptance (e.g. contributing to the IEA Wind TCP Task 28) [7].

In 2017, 95.97 million EUR (115.2 million USD) were spent on 86 new wind energy research projects supported by the Federal Ministry for Economic Affairs and Energy BMWi on the basis of a decision of the German Bundestag.

Compared to 86.24 million EUR (103.4 million USD) in 2016, this continues a steady increase in funding over the past years (see Figure 3). The 354 ongoing wind energy research projects created a funds flow of 75.11 million EUR (90.1 million USD) in 2017. All of these projects emphasize application-oriented wind energy research within the effective Sixth Energy Research Programme of the Federal Government [7].

Ongoing work within the Renewable Energy Research Networks engaged German wind energy experts in the process to create the next (Seventh) Energy Research Programme of the Federal Government. This included the research community, industry representatives, and political stakeholders. The Research Networks conducted this process by means of information exchange, transparency, and dialogue on open R&D issues [16].

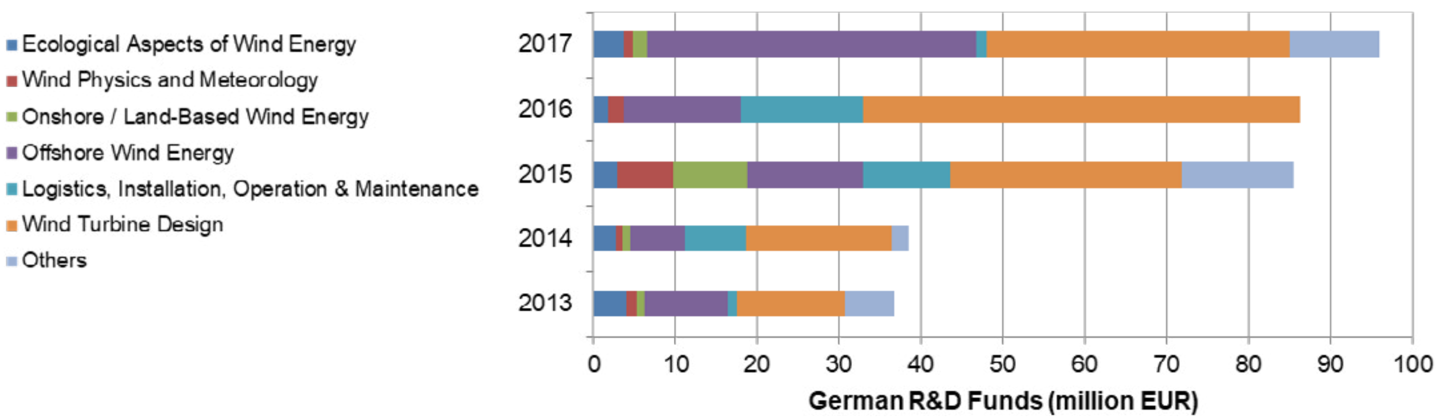

Figure 3. Development of German R&D funds from 2013–2017 (Source: Federal Ministry for Economic Affairs and Energy BMWi)

National Research Initiatives & Results

WEA-Akzeptanz: Senvion and Leibniz University Hannover are collaborating to develop an acoustic global model which captures both sound generation (at the rotor, wind turbine components, or nacelle) and sound propagation up to the receiver, under realistic atmospheric conditions. This project uses an interdisciplinary approach to combine sound generation, sound emission, and sound propagation with a psychoacoustic evaluation at the receiving point.

This model also includes a psychoacoustic evaluation of annoyance for the calculated sound emissions. To validate the different submodels and the global model, detailed field tests under varying environmental conditions are conducted. In addition, the influence of different operational conditions, as well as suitable methods for noise reduction, will be evaluated.

Finally, a psychoacoustic assessment and an acoustic simulation of the wind park during the early planning phase shall be made with 4 million EUR (4.8 million USD) from the Federal Ministry for Economic Affairs and Energy BMWi [7].

PRONOWIS: Schaeffler Technologies is coordinating a project to upgrade and install sensor components to develop a practical condition monitoring system for the early detection of white edging cracks (WEC) on wind turbine drivetrains. The sensor components will be trained on damage patterns of the drivetrain component using an extensive screening of existing records from field facilities. Missing results on materials and lubricant analysis are being developed in parallel.

The variables describing the damage patterns serve as input variables for the installation and calibration of the probes on the test benches at the Center for Wind Power Drives CWD at RWTH Aachen University. The result will be a functioning and on-WEC damage pattern scaled condition monitoring system. The Federal Ministry for Economic Affairs and Energy BMWi is funding this project with 1.9 million EUR (2.3 million USD) [7].

TopWind: This project develops new approaches, such as the integration of active elements, to influence the flow and affect the aerodynamics of rotors. The project is an initiative of multiple partners, including research institutes, universities, industrial enterprises and SMEs, coordinated by Fraunhofer Institute for Electronic Nano Systems ENAS. The intention is to develop concepts for actively influencing the flow around wind turbine rotor blades, based on novel structure-integrated fluidic actuators, which permit an adaptation of aerodynamics. The Federal Ministry for Economic Affairs and Energy BMWi is funding this project with 3.7 million EUR (4.4 million USD) [7].

The Federal Ministry of Education and Research (BMBF) also supports basic material research. The "Materials Research for the Energy Transition" initiative aims to extend wind turbine lifetimes, increase reliability, and reduce energy costs [25].

Test Facilities & Demonstration Projects

In the "**marTech**" project, the Leibniz University of Hanover and Technical University of Braunschweig are testing and developing maritime technologies in regard to wave current soil interaction. This includes analyses of substructures of offshore wind turbines, hydroelectric power, and wave/tidal energy systems within a significantly extended, large-scale test facility in the so-called Large Wave Flume in Hannover. There, three pilot projects with wave-energy converters, filter and sealing sheets, and a scour protection system will be planned and conducted together with industrial partners under realistic environmental conditions. The Federal Ministry for Economic Affairs and Energy BMWi is funding this project with 35.2 million EUR (42.2 million USD) [7].

The "**HiPE-Wind**" project analyzes multidimensional loading of high-performance electronics in wind turbines. The complete converter systems in 10 MW wind turbines will be exposed to precisely definable loads in a climatic chamber to extend their service life and prevent failures. The project partners (University of Bremen and Fraunhofer IWES) are researching how environmental conditions are transferred to the converter inside the turbine, thereby affecting internal components and impacting the system's service life. The accelerated aging of converter components in the test laboratory indicates weaknesses in the system hardware which are subsequently analyzed [24]. The Federal Ministry for Economic Affairs and Energy BMWi is funding this project with 11.57 million EUR (13.87 million USD) [7].

Collaborative Research

The Federal Ministry for Economic Affairs and Energy BMWi is Germany's contracting party in the IEA Wind TCP. German research institutions and industry representatives attended 13 of 15 active research tasks in 2017. All of Germany's Task participants also execute nationally-funded projects in their related topics, benefitting the mutual worldwide information exchange within their IEA Wind TCP Tasks. Representatives from the University of Stuttgart led Task work as the operating agent in Task 32 Lidar Systems for Wind Energy Deployment.

Germany is also involved in the European Commission's Strategic Energy Technology Plan and takes part in the Offshore Wind Energy Working Group. German industry and research representatives contribute to the European Technology and Innovation Platform (ETIPWind), support the European Energy Research Alliance (EERA), and participate in the European Academy of Wind Energy (EAWE). The "Framework Programme 7" is still working on several European-funded wind energy projects, as well as "Horizon 2020", which includes contributions by highly motivated German participants. Furthermore, the German Federal Government is enabling bi- and multilateral research projects via the so-called "Berlin Model".

In the "New European Wind Atlas (NEWA)" ERA-Net Plus project, 30 partners from eight countries are collaborating to create a new, freely-accessible wind atlas covering the European Union, Turkey, and coastal waters up to 100 km offshore. The wind atlas will contain site-specific wind resources on a 50-m grid, mesoscale time-series on a 3-km grid, and a web interface with maps as well as information on uncertainties and extreme winds. This project will develop and publicly distribute an open-source model chain. The wind atlas is validated against and complemented with atmospheric flow experiments in various kinds of terrain. For example, the Perdigao experiment, a joint field campaign with U.S. partners, is one of the most extensive meteorological campaigns in complex terrain in history. The Federal Ministry for Economic Affairs and Energy BMWi is funding the NEWA project with 2.21 million EUR (2.65 million USD).

IMPACT OF WIND ENERGY

Environmental Impact

In 2017, wind energy generated 106.6 TWh of electricity in Germany. This met 17.7% of national electricity demand and avoided 71 million tons of CO_2 equivalents. Overall, wind energy is the single largest source of renewable energy, and it accounts for 37% of total CO_2 equivalents avoided by all renewable energy sources.

Economic Benefits & Industry Development

Renewable energy has a significant economic impact and wind energy is a large part of that. In 2017, the investment costs of land-based wind power equaled 7.77 billion EUR (6.81 billion USD in 2016). In addition, 3.24 billion EUR (3.32 billion EUR in 2016) has been invested in offshore wind power.

The operation of land-based wind power and offshore wind power led to a turnover of 2.09 billion EUR (1.88 billion EUR in 2016) and 0.42 billion EUR (0.35 billion EUR), respectively. Thus, in 2017 the total domestic wind power turnover was 13.52 billion EUR (12.36 billion EUR in 2016) [1].

In early 2018, a new study presented an in-depth analysis of employment in the energy sector. According to those most recent numbers, 133,000 persons were employed in the land-based wind energy sector in 2016, and 27,200 were employed in the offshore wind energy sector. Due to strong wind-energy deployment in 2017, we anticipate that employment this year was similar to the previous year [14].

NEXT TERM

To correct for the uncertainty in wind turbine deployment in Germany which was introduced by the large share of non-permit projects in the 2017 auctions, the auctioning system has been altered. From 2018 forward, bidding without permit will no longer be possible. Furthermore, additional auctioning rounds are currently under discussion.

Forty years after the first German Energy Research Programme of the Federal Government was launched, an amendment to the Sixth Energy Research Programme (which includes, amongst other renewable energies and energy efficient technologies, all aspects of wind energy R&D topics) is foreseen for a period of another five years. This Seventh Framework Energy Programme shall be adopted in 2018 and start in 2019.

Wind energy continues to be central to 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.

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Opening photo: Rotor blade from the SmartBlades2-Project (Source: Fraunhofer IWES, Photo Credit: Pascal Hancz)

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Greece

Table 1. Key Statistics 2017, Greece	
Total (net) installed wind power capacity	2,652 MW
Total offshore capacity	0 MW
New wind power capacity installed	278 MW
Decommissioned capacity (in 2017)	---
Total electrical energy output from wind	4.7 TWh
Wind-generated electricity as percent of national electricity demand	8.4%
Average national capacity factor	---
Target	7,500 MW by 2020

OVERVIEW

In 2017, Greece continued to see encouraging growth in its wind energy sector. The country installed approximately 278 MW of new wind power capacity (Table 1 and Figure 1). According to the Greek Wind Power Energy Association (ELETAEN), this 9% increase brings the total installed wind capacity to 2,652 MW [2].

The electrical output from wind generation in Greece totaled 4.7 TWh—meeting approximately 8.4% of national demand [1]. At the close of 2017, a total of 187 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.

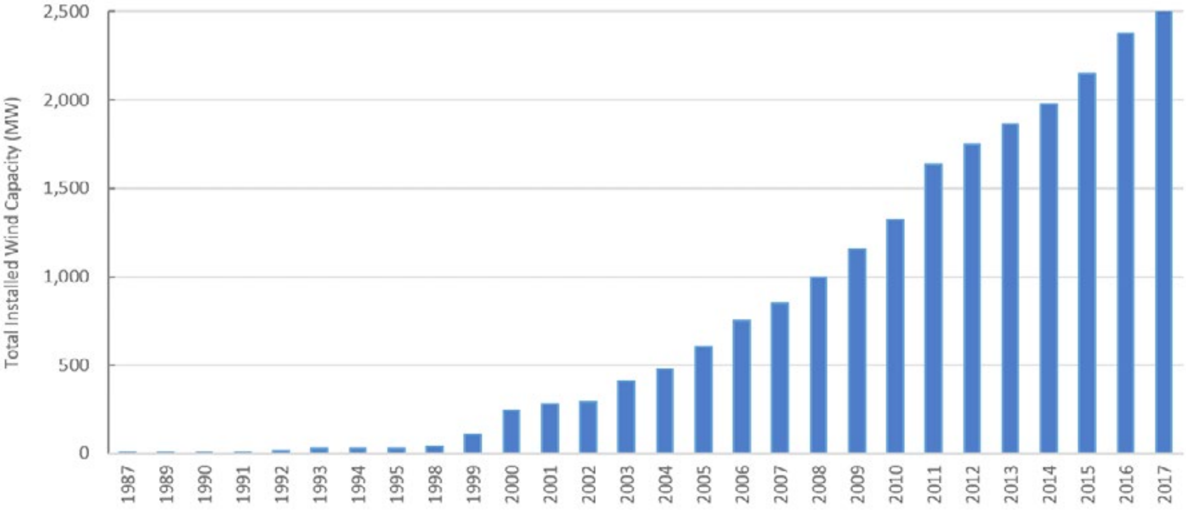

Figure 1. Annual cumulative capacity for Greece (Source: Hellenic Wind Energy Association)

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Opening photo: Skopies wind farm (Courtesy: Iberdrola)

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Ireland

Table 1. Key Statistics 2017, Ireland	
Total (net) installed wind power capacity	3.37 GW
Total offshore capacity	0.03 GW
New wind power capacity installed	0.57 GW
Decommissioned capacity (in 2017)	0 GW
Total electrical energy output from wind	7.44 TWh
Wind-generated electricity as percent of national electricity demand	22.8%
Average national capacity factor	27.5%
Target	40% RES-E by 2020

OVERVIEW

Wind energy in Ireland continued on a strong growth trajectory in 2017. The country added unprecedented 568 MW of wind power capacity— a 20% increase that was almost 50% greater the previous annual record. Wind energy accounted for 24.8% of national electricity demand, an 18.7% increase from 2016. A high level of construction continues to build out capacity under the now closed, REFIT support scheme, which will help deliver on Ireland's 2020 targets.

The high-level design of a new auction-based renewable electricity support scheme was published in 2017. Community investment in and ownership of renewable electricity plants is central to the design of the new scheme.

Extensive changes are under way in the electricity market, including a revamped capacity payment mechanism and new system services arising from the "DS3" R&D program. Wind plants were qualified to tender for many of the latter services in tests during 2017.

SEAI formed the Irish Wind Energy Research Network in 2017, which held its first meeting in September. The network aims to connect and provide continuity to research projects, as well as inform national wind energy research strategy. It will initially achieve this by providing a forum to highlight recent research projects and to facilitate informal networking among researchers.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

Meeting the EU's 2020 renewable energy targets remains the primary driver of Ireland's national policy. Wind energy will deliver almost 50% of the national renewable energy target and over 80% of the renewable electricity target.

SEAI's 2017 report *Ireland's Energy Projections, Progress to Targets, Challenges and Impacts* found that, in the current trajectory, the targeted renewable energy contributions to transport and heat will experience significant shortfalls and the renewable electricity (RES-E) target will experience a more modest shortfall [1].

As wind energy will make such a major contribution to both the renewable electricity and overall renewable energy targets, continued build out of approved projects is of paramount importance. It is also important to obtain fleet-wide efficiency improvements for existing wind farms, as this will significantly reduce shortfall on the target.

Following the closure of the REFIT II scheme, the government initiated the high-level design of a replacement Renewable Electricity Support Scheme in 2016. The DCCAE published a *Public Consultation on the Design of a new Renewable Electricity Support Scheme in Ireland* in September 2017, as well as the supporting reports *Economic Analysis to Underpin a New Renewable Electricity Support Scheme in Ireland*, *Renewable Technology Input Data*, and the SEAI study *Assessment of models to support community ownership of renewable energy in Ireland* [2-5].

The EU State Aid rules primarily shaped the proposed high-level scheme design, requiring that the RES-E support levels be set through competitive auctions and that all new RES-E schemes provide support in the form of a premium, in addition to the market price. The proposed scheme will be administered through technology-neutral auctions for a floating feed-in premium (FIP) to supplement the market price to give the auction clearing price.

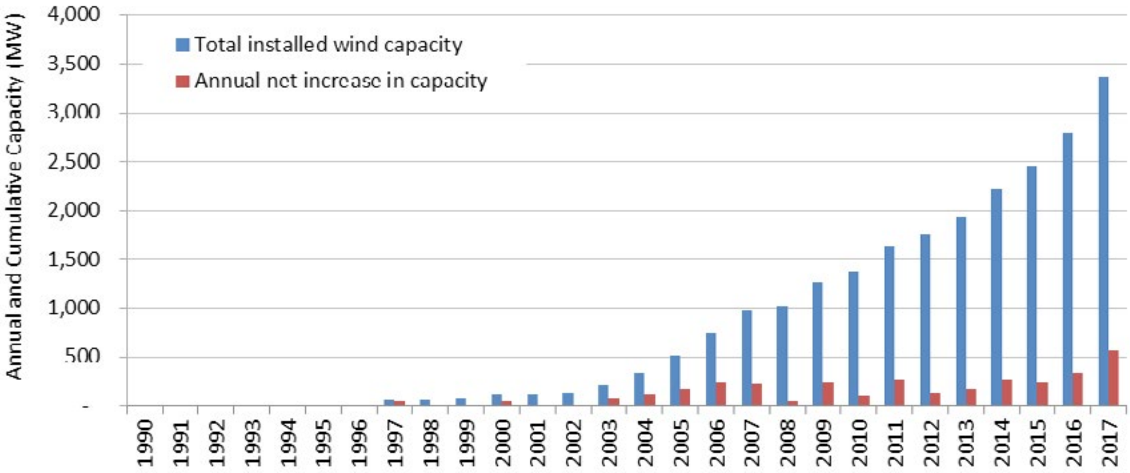

Figure 1. Cumulative and annual wind power generation capacity 1990-2017

It will also promote community investment in, and ownership of, renewable electricity projects by providing specific requirements for such projects. For smaller community projects (below 6 MW for wind), a floating FIP should be made available. The scheme design also recommends a community benefit payment of 2 EUR/MWh (2.4 USD/MWh).

Progress & Operational Details

Ireland constructed 568 MW of new wind power capacity in 2017, bringing the nation's total capacity to 3,368 MW. This was almost double the previous annual installation record and represented a 20% increase in installed capacity.

Wind-generated electricity amounted to 7,441 GWh (24.8% of total electricity demand) in 2017—an 18.7% increase on 2016. Wind curtailment rose to 3.7%, increasing 32% on 2016 levels [6]. However, these statistics may underrepresent the potential output of the installed wind plants; 2017 was a low wind year with an average capacity factor of 27.5%, which is 2.5% lower than the long term average (around 30%).

There were significant project acquisitions in 2017, with both approved projects and developed assets being traded. Wind farm operational costs have been rising in recent years, primarily due to local tax increases. There was also an increase in the number of wind farms offering community benefit schemes in line with government recommendations.

Construction of the 169-MW Galway Wind Park, the largest Irish wind farm to date with 58 Siemens SWT-3.0-101 D3 direct-drive wind turbines, was completed in 2017 [7]. This, along with several other large projects, contributed to 2017 being a record year. Senvion wind turbines were used on Irish wind farms for the first time in 2017.

Matters Affecting Growth & Work to Remove Barriers

The 2017 construction increase reflects the impetus to complete projects before 2019 for inclusion in the REFIT II support scheme. Legal challenges to planning decisions have caused delays, creating a backlog of projects awaiting construction. The provision of grid connections by the TSO and DNO under the group processing approach determines the construction schedule for consented projects, and resourcing this amid the peak in construction activity has been challenging.

Terminating the REFIT support mechanism may lead to a gap in support schemes while the replacement RESS is finalized. As any gap may coincide with the final years of the national target period, it may compromise target achievement. While there was an unprecedented peak in deployment in 2017, construction activity will likely tail off toward 2020.

To conform with the EU Target Market model, Ireland will transition from the current Single Electricity Market to the new Integrated Single Electricity Market in 2018, which will *inter alia* involve adapting both power purchase agreements and the REFIT support for wind farms [8].

The government published proposed new arrangements for REFIT settlements in 2017 [9]. The continuous trading environment will also require wind farm operators to interact more intensively with the market than in previous years. The Single Market Operator, Eirgrid published proposals regarding arrangements for an agent of last resort in 2017 [10].

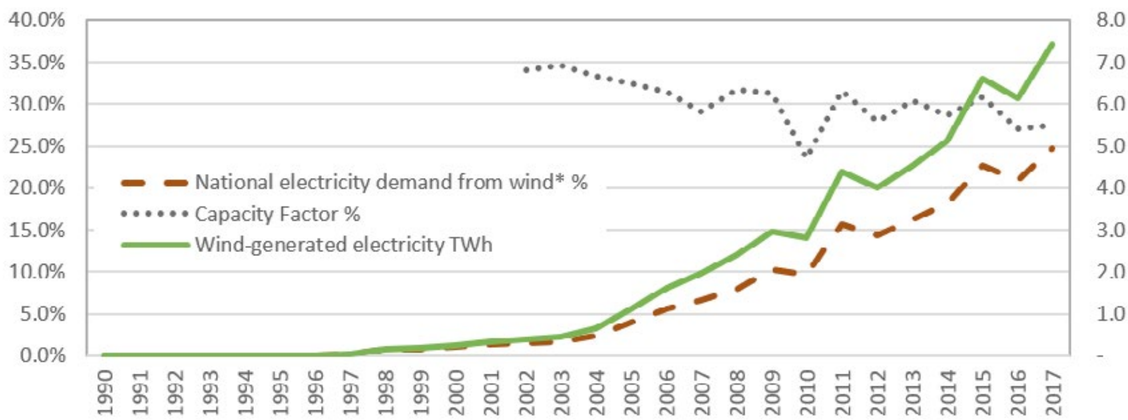

Figure 2. Wind-generated electricity, contribution to demand, and capacity factor, 1990-2017

Recent developments mean that the current connection policy for electricity generators in Ireland is no longer fit for purpose. The process, intended for smaller generators and experimental technologies, is vastly oversubscribed due to a surge in applications from small-scale solar projects, which can be subject to lengthy connection delays. Currently, over 36,000 MW of generators and other technologies are waiting to connect or gain a connection offer to a system with a peak demand of 5,500 MW.

The Commission for the Regulation of Utilities (CRU) began consultations on an enduring connection policy (ECP) framework in 2015. Key framework proposals were published in November 2017 for the first stage of ECP (ECP-1) including:
- Provide at least 1,000 MW of new connection offers under the 2018 batch
- Reserve up to 400 MW for DS3 systems services providers
- Require planning permission to enter the 2018 batch, but not from DS3 providers
- Remove the option to relocate capacity for all projects permanently, except to provide existing contracted projects one last opportunity to relocate to a permitted site.

R,D&D ACTIVITIES

National R,D&D Priorities & Budget

National R&D priorities for wind energy outlined in the 2015 energy research strategy include power system integration; development of smaller, cost-effective systems for community-based sustainable energy initiatives; and social acceptance of such technologies, focusing on models of community ownership/participation [12].

There is no specific wind energy research budget in Ireland, and the total R&D funding dedicated to wind energy in 2017 is unavailable. According to the nature of particular projects, wind energy research may be publicly funded by state bodies as outlined in the *IEA Wind TCP 2016 Annual Report.*

National Research Initiatives & Results

Wind research is most consistently funded by SEAI; in 2017, they funded the following projects under its R,D&D scheme:
- Legislative Mechanisms for Local Community Ownership and Investment in Renewable Energy Infrastructure
- Analysis of Local Obstacle Impacts on the Energy Performance of Large Scale Wind Autoproducers in Peri-Urban Locations, Based on Multi-Annual SCADA Data
- Wind Autoproduction Micro-Siting Guidelines
- An Economic Analysis of Wind Farm Externalities and Public Preferences for Renewable Energy in Ireland

The following offshore wind R&D projects were funded under the SEAI Ocean Energy program:
- Kite System Active Systems Trials – Aeolus Surveillance Platform
- Gap Analysis of Irish Port & Harbour Infrastructure for Renewable Energy Deployment
- BluWind Floating Wind Evaluation Galway Bay 1:6 Scale Prototype Demo

Eirgrid continued implementing its DS3 program, which adapts the electricity system for high-variable renewable input (primarily wind energy). In 2017, Eirgrid completed the Smart

Figure 3. A Cappawhite B 4xV105 turbine (Source: Dr. Joe Jellie, Construction Manager, ABO Wind Ireland

Valve project and published a *DS3 System Services Proven Technologies List* (December 2017), with wind power plants being eligible for seven categories of service [13, 14].

Test Facilities & Demonstration Projects

Eirgrid completed trials in 2017 to verify the capabilities of power-generation and other technologies to provide newly-defined system services. Successful technologies could participate in tendering for new system service contracts. Wind power plants performed well in the trials, qualifying to provide the following services: Fast Frequency Response (FFR), Primary Operating Reserve (POR), Secondary Operating Reserve (SOR), Tertiary Operating Reserve 1 (TOR1), Fast Post Fault Active Power Recovery (FPFAPR), Steady State Reactive Power (SSRP), and Dynamic Reactive Response (DRR).

Two new meteorological lidar units were installed in western and southwest Ireland in 2017 [15]. These will provide a new public domain source of wind speed measurement data for higher altitudes.

Collaborative Research

Ireland participates in seven IEA Wind TCP research Tasks:
- Task 11 Base Technology 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 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN)
- Task 36 Forecasting for Wind Energy
- Task 39 Quiet Wind Turbine Technologies

Ireland leads Task 28 on the Social Acceptance of Wind Energy and led the formation of the new Task 39 on Quiet Wind Turbine Technology in 2017. SEAI initiated the Irish Wind Energy Research Network (IWERN) in September 2017 to provide a forum where the research community can regularly meet, facilitate collaboration and new research initiatives, and highlight recent research achievements. It will also provide a connection to the IEA Wind TCP research Tasks, as well as an opportunity to become involved in them.

IMPACT OF WIND ENERGY

Environmental Impact

Wind energy displaced [2718] kT of CO_2 emissions in 2017. Wind energy resulted in the greatest avoided emissions of any of the renewable energy sources in Ireland.

Economic Benefits & Industry Development

As an indigenous source of energy, wind energy contributes to Ireland's energy security and will become the single largest indigenous source of electricity by 2020. Wind energy displaced an estimated 200 million EUR (240 million USD) of fossil fuel imports in 2017.

Wind energy deployment also makes a favorable impact on national economic indicators. Displacing fossil fuel imports improve the trade balance, installing wind turbines increases capital stock and/or foreign direct investment, and constructing wind farms increases government taxation revenues through several direct and indirect channels.

NEXT TERM

Construction of approved REFIT II projects will continue through 2018 and 2019, though at a lower rate than in 2017. The detailed design of the future Renewable Electricity Support Scheme will be completed in 2018. Once EU State Aid approval is obtained, the technology neutral auctions may commence. This may introduce a new era of opportunity for wind energy development; offshore wind, which was excluded from prior support schemes, will be eligible to compete in the auctions.

The new scheme will also place a particular emphasis upon community investment in, and ownership of, wind farms. SEAI will revamp its R,D&D funding scheme in 2018. Changes to the scheme will include partnering with other agencies to co-fund projects and specific calls for defined projects.

Particular calls for wind energy projects in 2018 will include:

- Financial structures to support citizen and community participation in renewable energy projects
- Forecasting tools to assist variable renewable electricity plant operators in managing their financial exposure to imbalances in the I-SEM
- Feasibility studies and demonstrations of wind farm efficiency improvements
- Wave-ocean-atmosphere coupled weather forecasting
- Research supporting Ireland's participation in the IEA Wind TCP Task 39 Quiet Wind Turbine Technology

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Opening photo: ABO-Wind's Cappawhite B wind farm with four V105 turbines in Tipperary, Ireland (Photo credit: ABO-Wind)

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Author: John Mc Cann, SEAI, Dublin, Ireland.

Italy

Table 1. Key Statistics 2017, Italy	
Total (net) installed wind power capacity	9.5 GW
Total offshore capacity	0 GW
New wind power capacity installed	0.253 GW
Decommissioned capacity (in 2017)	0 GW
Total electrical energy output from wind	17.5 TWh
Wind-generated electricity as percent of national electricity demand	5.5%
Average national capacity factor	21.6%
Target	12,000 MW land- based; 680 MW offshore by 2020; 40 TWh wind energy production by 2030

OVERVIEW

In 2017, new installed wind power capacity in Italy totaled 253 MW. Cumulative installed capacity at the end of the year reached approximately 9.5 GW.

Italy deployed 114 new turbines, bringing the total number of installed wind turbines over 6,734. Wind-generated electricity accounted for 17.5 TWh, corresponding to about 5.6% of the country's total demand. As usual, foreign producers supplied most of the new multi-megawatt turbines.

Wind energy R,D&D activities have been carried out by the following entities: universities; Ricerca sul Sistema Energetico (RSE); the National Research Council (CNR); and the National Agency for New Technologies, Energy, and Sustainable Economic Development (ENEA).

In the period 2016-2017, Italy set an 800-MW quota for land-based wind power capacity assigned through tender. At the end of 2017, the new expected decree, which sets the rules for renewable production incentives, had not yet been published. The new National Energy Strategy (SEN) was published on 10 November 2017, setting a wind energy production target of 40 TWh (mostly from land-based plants) by 2030, including the repowering and revamping of end-of-life wind farms.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

The SEN 2017 outlines national objectives and policies for Italian energy systems by 2030. Renewable energy sources will play a central role to reach or exceed the environmental and decarbonization objectives by 2030 as defined at European level, and in line with the COP21 targets, in a sustainable way. Continued cost reduction for renewables in the electricity sector, the accumulation systems, and power grid adaptations will support the increased renewable energy penetration for electric and heating power. Technological advances are expected to further reduce wind energy costs by 10-25%.

In 2009, Italy set a binding national target of 17% of overall annual energy consumption from renewable energy sources (RES), which included a target of 12.68 GW (12.0 GW land-based and 0.680 GW offshore) installed wind power capacity and a target of 20 TWh/yr (18 TWh/yr land-based and 2 TWh/yr offshore) for electricity production.

In order to reach the new target of 55% renewable penetration on the national electricity demand) by 2030, the SEN set a target of 40 TWh/yr of wind energy production (mostly land-based). This includes repowering and revamping of end-of-life wind farms. Therefore, Italy can expect significant increase in wind power capacity in the coming years.

The main issue surrounding the present incentive mechanism supporting renewables (decreed 6 July 2012) is the 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 tender (until the annual quota is reached), which are granted over the plants' average conventional lifetime of 20-25 years.

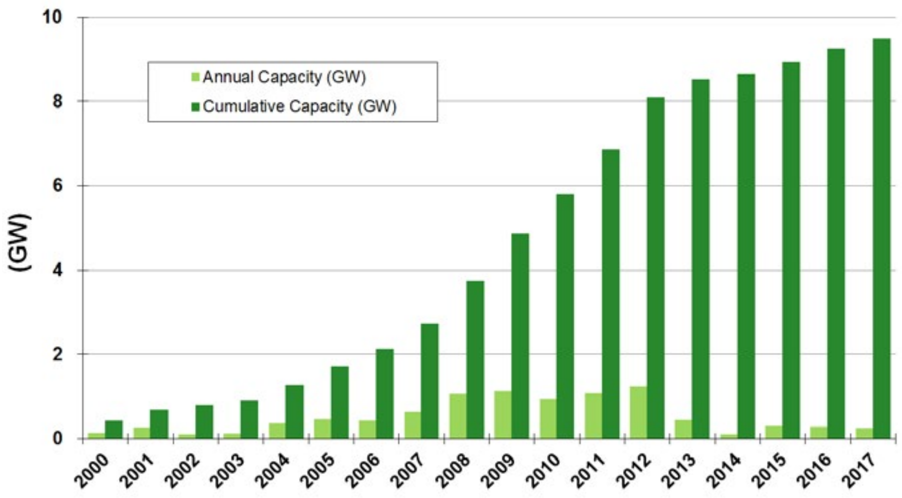


Figure 1. Annual and cumulative wind power capacity trends in Italy (2000-2017)

The 2016 implementing decree set an 830-MW quota for wind power capacity (800 land-based and 30 MW offshore) for 2016-2017. The incentive tariff for wind power plants depends on the size—for example, for plants greater than 5 MW, the tariff is 110 EUR/MWh (230 USD/MWh) for land-based and 165 EUR/MWh (198 USD/MWh) for offshore; for plants size between 6 and 200 kW the tariff is 160 EUR/MWh (192 USD/MWh). No addtional decrees were approved in 2017 for the next period.

Progress & Operational Details

According to the National Wind Energy Association (ANEV), Italy installed a new net wind power capacity of 252.85 MW in 2017. Cumulative installed capacity at the end of 2017 reached 9.50 GW, including decommissioning and repowering. All of Italy's current wind power capacity is land-based. The annual installed wind power capacity is substantially driven by the annual quota introduced in the 2012 decree (Figure 1).

TERNA, the national TSO, estimates that wind-generated electricity in 2017 totaled 17.5 TWh—5.5% of Italy's total electricity demand (total consumption plus grid losses) [1]. Italian wind-generated electricity trends are shown in Figure 2.

Most installations are in the southern regions of Italy, due to wind resource availability (Figure 3). In 2017, new wind power capacity was mainly installed in the Basilicata (59%), Calabria (19%), and Campania (11%) regions.

In 2017, 14 wind farms were grid-connected with capacities between 0.8 MW and 60 MW. Italy installed 114 new turbines, bringing the country's total to 6,734 units. The wind turbines installed during the year averaged 1.94 MW (maximum 3.2 MW); the average size of all wind turbines in Italy is 1.4 MW.

The average capital cost is approximately 1,500 EUR/kW (1,580 USD/kW) for wind farms between 200 kW and 60 MW and 1,340 EUR/kW (1,411 USD/kW) for wind farms larger than 5 MW. For small wind plants higher costs are reported [2].

Matters Affecting Growth & Work to Remove Barriers

The main issue affecting growth is the uncertainty about the rules of the future incentive mechanism. Moreover, tender winners for large land-based wind farms have two years to complete their installation and grid-connection. However, many of these plants are not realized resulting in a lower-than-expected annual installed wind capacity.

The reduced incentive tariff for small wind turbine will probably negatively affect the growth of these installations in the next years. Concerning offshore wind plants, the 30-MW quota set by the 2016 decree affects the only authorized offshore wind plant, which will be built in Taranto harbor.

The high-density population, complex terrain, widespread tourism, and landscape impact could also affect the acceptance and growth of further wind capacity in Italy.

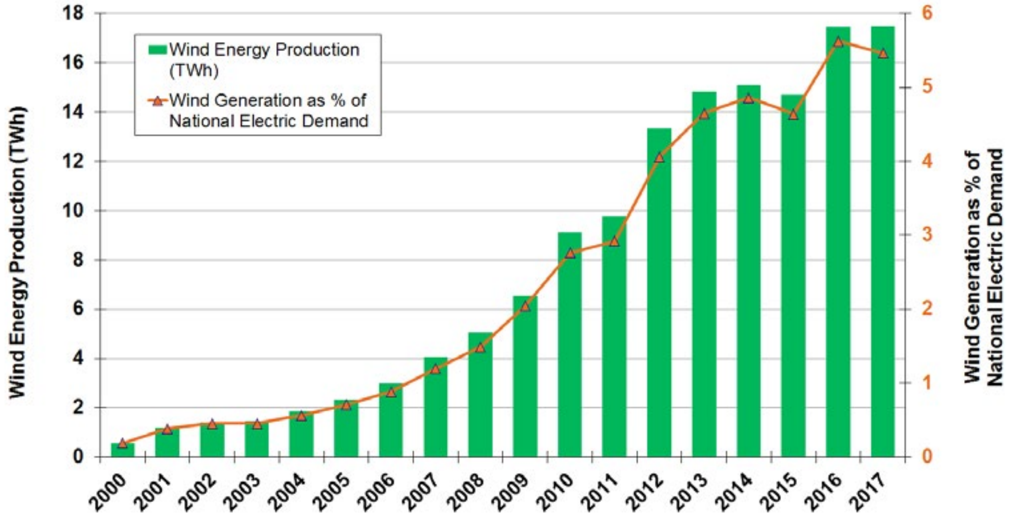


Figure 2. Wind-generated electricity production trends in Italy (2000-2017)

National R,D&D Priorities & Budget

There is no coordination of wind energy R,D&D activities at the national level; however, many organizations are involved in wind energy research. 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.

In 2017, Italy promoted Mission Innovation—an initiative which aims to reinvigorate and accelerate global clean energy innovation. Research funds for affordable clean energy are expected to increase before 2021.

National Research Initiative & Results

The POLI-Wind group has been working on wind turbine aeroservoelasticity, 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 (10- to 20-MW) wind turbines. 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.

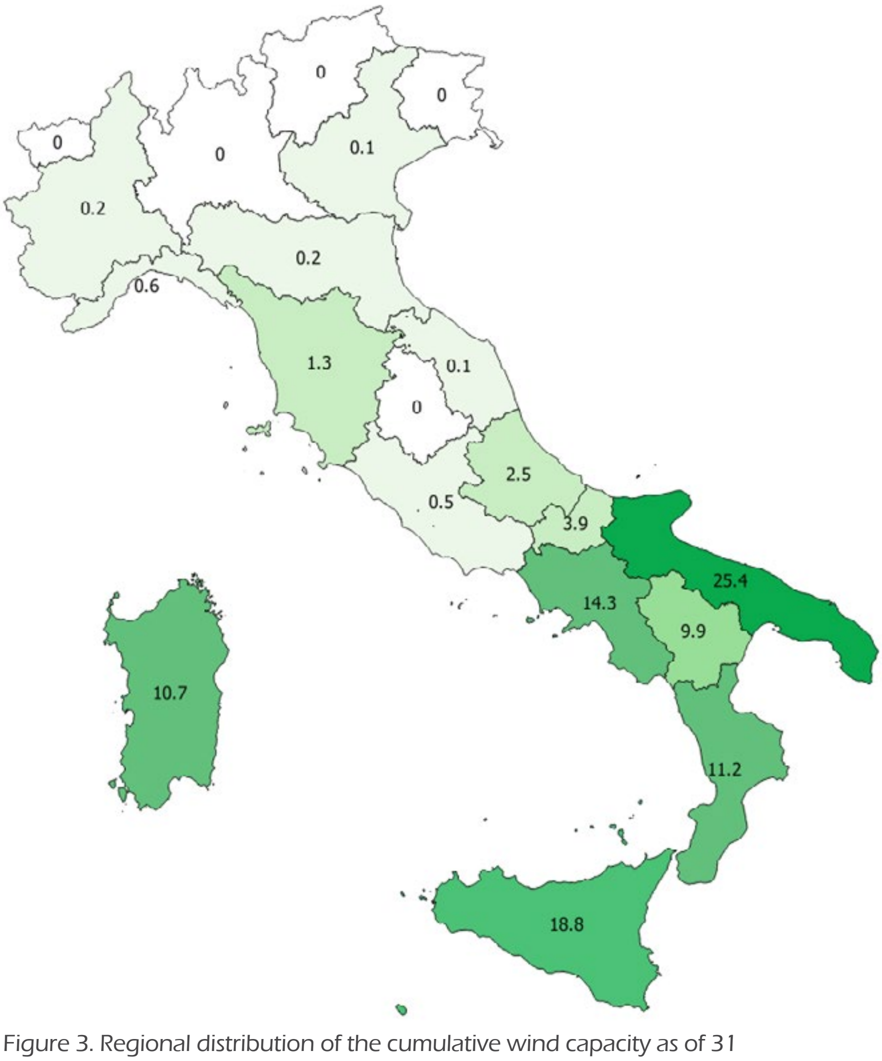


Figure 3. Regional distribution of the cumulative wind capacity as of 31 December 2017, by percent

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+, which studies floating substructures for 10-MW wind turbines.

The Aircraft Design and AeroflightDynamics Group (ADAG) of the University of Naples Federico II, in cooperation with Seapower scrl, has been involved in the design, development, installation, and field testing of small and medium vertical axis wind turbines (VAWT) and horizontal axis wind turbines (HAWT), for more than 25 years. Their research adheres to IEC-61400-1 standards and 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
- Optimization of composite manufacturing techniques to minimize the cost of blades

In 2017, the University of Florence, through its Interuniversity Center for Building Aerodynamics and Wind Engineering (CRIACIV) developed an accurate simulation tool for large fixed-bottom and floating offshore wind turbines. The results are contained in three PhD dissertations (Stabile, Giusti, Mockute). Their most recent original findings discuss the implications that nonlinear wave models have on the extreme and fatigue loads of offshore wind turbines. CRIACIV collaborated with the National Research Council's Marine Technology Research Institute (CNR-INSEAN), as well as other national and international research institutions worldwide. CRIACIV is a participant in Horizon 2020 projects such as MARINET2 and MSCA-ITN-AEOLUS4FUTURE, as well as the COST Action TU1304 WINERCOST. In 2017, CRIACIV also prepared the Final Conference of the WINERCOST Action in Catanzaro (www.winercost18.eu).

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 boundary-element methods (BEM) and finite-element methods (FEM) 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 since 2013 (www.owemes.org). OWEMES is devoted to promoting offshore wind and ocean energy sources and cooperates with several Italian universities and research institutes.

The University of Trento is active in small turbine design and testing and conducts their tests on their own experimental field. Dedicated research on wind energy exploration in cold climates and anti-icing systems for wind turbines have been running here for more than ten years.

The University of Perugia (Department of Engineering) is working on wind turbine and wind farm operation analysis, as well as diagnostic and loads. The work is based on real operation data, thanks to cooperation with wind farm operators and scaled experiments in the wind tunnel. Currently, the research activities are supported by the Progetti di Ricerca di Interesse Nazionale (PRIN), the Italian funding source for research projects of national interest). SOFTWIND (Smart Optimized Fault Tolerant Wind Turbines) and the OPTO WIND (Operational Performances and Technical Optimization of WIND turbines) project are funded by the CRP Foundation.

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 forecasting, production forecasting, grid integration, resource assessment through measures and models, and an empowered wind and renewable atlas.

The CNR currently involves two institutes in its wind energy activities, which are in the frame of national and EU FP7 projects. The 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, putting them in the frame of EU MARINET projects. Under the IRPWIND project, CNR-ISAC manages the Mobility program, an innovative schema to facilitate cooperation between the experienced researchers participating in the European Energy Research Alliance's wind energy joint program (EERA JP WIND).

The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) tested anemometers and small wind turbines at its wind tunnel facility. ENEA is also involved in developing non-destructive evaluation methods for materials and components, based on x-ray high-resolution computed tomography.

KiteGen is a company involved in the development, industrialization, and production of a 3-MW high altitude wind generators in their final form with a predictable time to market—a result that has changed the current corporate mission.

The complexity of the Power Wing program required some industrial companies specialized in complementary fields to join KiteGen, including a composite materials company with twenty years' experience in the field of advanced composites for the aeronautics sector.

The role of the specialist composite company is to support, produce, and industrialize products that require improvement in terms of technology and performance. This can be achieved by replacing traditional materials with advanced composite materials, or by designing components made with these new technologies. The KiteGen wing, which is a completely new and extreme object, can reap the benefits of this extensive experience, as well as the specialized equipment designed for working on large monolithic composites.

Collaborative Research

RSE has long been the Italian participant in IEA Wind TCP Task 11 Base Technology Information Exchange. TERNA participates in Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power. Polytechnic of Milan participates in Task 30 Offshore Code Comparison Collaboration, Continued, with Correlation (OC5).

CNR is a full participant in EERA's joint program on wind energy, while Polytechnic of Milan and RSE are associated participants.

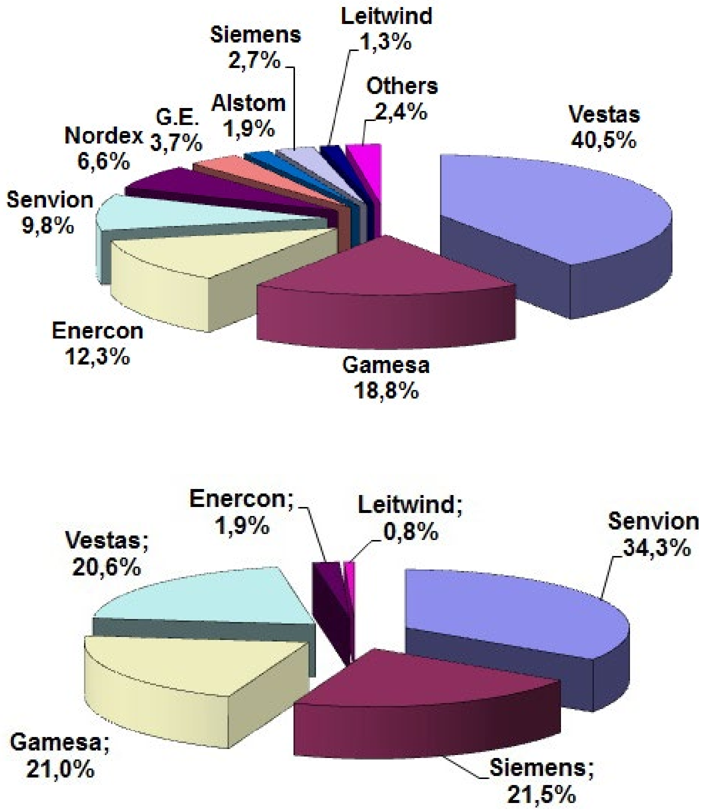


Figure 4. Market share of the cumulative (top) and annual (bottom) wind turbine manufactures in Italy

IMPACT OF WIND ENERGY

Environmental Impact

According to the Gestore dei Servizi Energetici (GSE), substituting one MWh produced by fossil fuels with one produced by wind energy avoids 536 kg in CO_2 emissions [2]. In 2017, Italy's wind-generated electricity avoided around 9.4 million tons of CO_2 emissions.

Economic Benefits & Industry Development

In 2017, the economic impact of wind energy in Italy was estimated around 3.3 billion EUR (4 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, and grid-connection) activities, contributed an estimated 339 million EUR (407 million USD). O&M of the online plants contributed approximately 350 million EUR (420 million USD). Finally, wind energy production and commercialization contributed approximately 2.6 billion EUR (3.2 billion USD).

In 2017, the number of jobs in the wind energy sector was estimated to be stable at 26,000 units, including direct and indirect involvement.

Concerning the owners/operators of the overall wind projects, the situation in Italy has not changed significantly from 2016 to 2017 [3]. There are four big players in the Italian wind energy market, whose shares exceed 5%: Erg Renew, Enel Green Power, Fri-el, and E2i Energie Speciali. Approximately 20 players have shares near or exceeding 1%, and several other small players account for the remaining half of the market. All the operators of the new installed capacity are not considered big players.

Foreign manufacturers strongly prevail in the Italian large-sized wind turbine market (Figure 4). The top three manufacturers of the capacity installed in 2017 were Senvion (34.3%, Siemens (21.5%) and Gamesa (21%). Leitwind is the only Italian manufacturer of large-sized wind turbines and accounted for 0.8% of the 2017 market and 1.3 % of the overall installed capacity. Vestas has two production facilities in Taranto. Italian firms still maintain a significant presence in the small-sized wind turbine market (up to 200 kW).

NEXT TERM

According to Gestore dei Servizi Energetici which supports the production of electricity from renewable sources through various incentive mechanisms, about 100 wind plants (1.4 GW) will exit the incentive mechanism between 2017 and 2019, reducing the total incentivization cost by 230 million EUR (276 million USD) [2]. From 2018-2020, almost 760 MW, mostly due to the 2016 decree, are expected to be commissioned for a total incentive cost of almost 40 million (48 million USD).

In 2018 the installation and commissioning of the first offshore (actually nearshore) wind farm in Italy is expected. The 10-turbine, 30-MW plant will be sited in the Taranto harbor, very close to the dock [4].

The Italian Community of the Offshore Wind (ICOW), is a collection of public and private stakeholders, universities, and public research institutes created under the authority of the newborn Cluster BIG (Blue Italian Growth). In agreement with the Cluster Energia, ICOW proposed a national strategy for the sustainable development of floating offshore wind in a document addressed to the Italian delegates of the SET Plan and the line ministries.

As a first step, ICOW identified the need for one or more testing sites in the Mediterranean Sea to develop innovative solutions for floating offshore wind and other marine renewable energy resources. These sites will be managed by the Cluster BIG, possibly reusing an oil and gas platform close to the decommissioning stage.

References

Opening photo: KiteGen's Power Wing, aerodynamic tests (on the right) and autoclave curing of the huge kevlar composites (on the left).

[1] Terna (December 2017). Rapporto Mensile sul Sistema Elettrico.

[2] GSE, "Il punto sull'eolico".

[3] ANEV, "Duemilasedici" brochure. Download from: www.anev.org/wp-content/uploads/2016/05/Anev_brochure_2016web.pdf

[4] www.offshorewind.biz/2017/06/14/senvion-turbines-for-first-offshore-wind-farm-in-the-mediterranean/

Author: Laura Serri, Ricerca sul Sistema Energetico (RSE S.p.A), Italy.

Japan

Table 1. Key Statistics 2017, Japan	
Total (net) installed wind power capacity	3,399 MW
Total offshore capacity	64.6 MW
New wind power capacity installed	169 MW
Decommissioned capacity (in 2017)	0 MW
Total electrical energy output from wind	5.8 TWh
Wind-generated electricity as percent of national electricity demand	0.64%
Average national capacity factor	19.5%
National wind energy R&D budget	6.9 bil JPY; 51 mil EUR; 61 mil USD
Target	10 GW wind power capacity by 2030

OVERVIEW

In 2017, Japan's total installed wind power capacity reached 3,399 MW, including 64.6 MW of offshore capacity. The annual net capacity increase was 169 MW. Total wind-generated electricity during 2017 was about 5.8 TWh, which corresponded to 0.64% of the national electricity demand (906.2 TWh).

Although the environmental impact assessment (EIA) review process has been streamlined, new wind farm projects (with an additional capacity of 16 GW) are still undergoing the EIA review process. Some projects are proceeding in port and ocean areas, where Japan has considerable potential for offshore wind farms.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

Following publication of The Fourth Strategic Energy Plan, the Ministry of Economy, Trade and Industry (METI) issued the Long-Term Energy Supply and Demand Outlook, which included an estimate for the power source mix in 2030 [1]. The projected share of wind energy in Japan's 2030 power source mix is 1.7%, or 10 GW of capacity, including 0.82 GW of offshore wind power. However, according to a Japan Wind Power Association (JWPA) report, wind energy capacity will probably exceed this share by the early 2020s.

Japan adopted a feed-in-tariff (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 FIT will last 20 years for wind power, including small wind and offshore wind power.

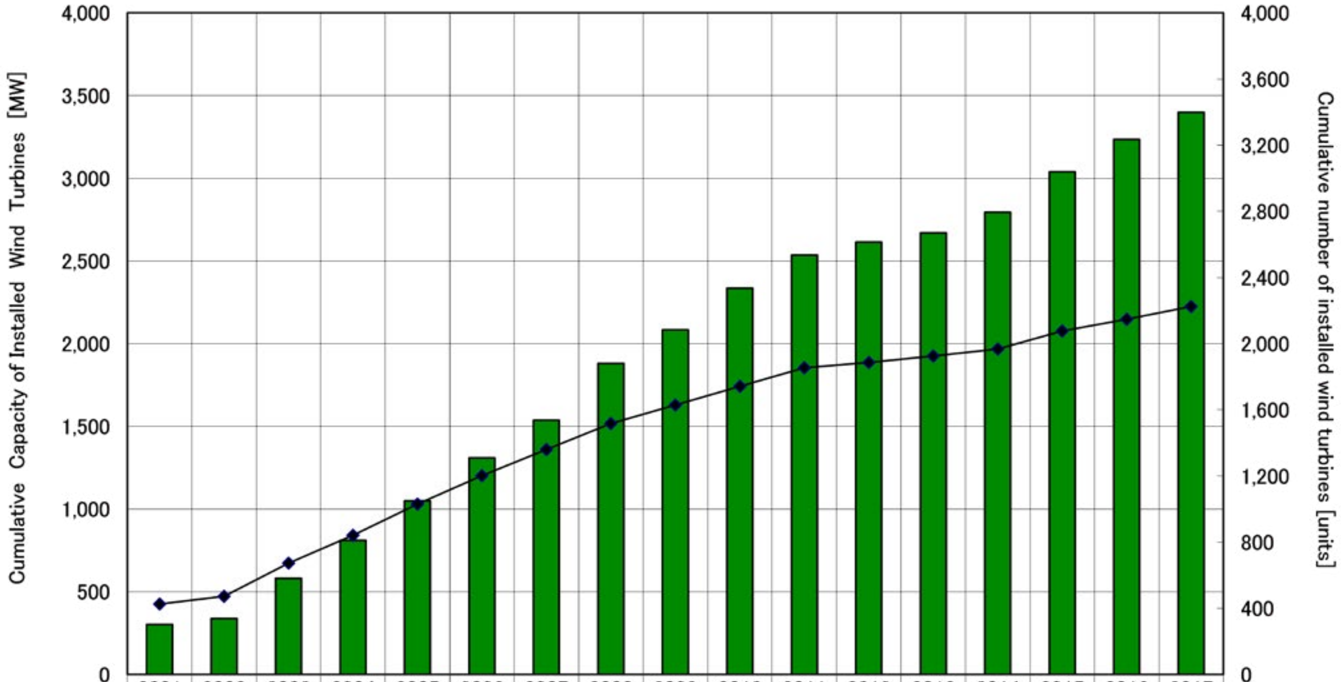
The tariff is reassessed every year, based on Japan's latest market situation. METI drafted a modified tariff for wind and solar power in 2016. With these modifications, the FIT for land-based wind would be reduced 1 JPY/kWh (0.007 EUR/ kWh; 0.009 USD/kWh) every fiscal year, from 21 JPY/kWh (0.165 EUR/ kWh; 0.19 USD/kWh) in FY 2017 to 19 JPY/kWh (0.14 EUR/ kWh; 0.17 USD/kWh) in FY 2019. The tariff for offshore wind would maintain a constant rate of 36 JPY/kWh (0.27EUR/kWh; 0.32 USD/kWh). METI also drafted a new tariff for repowering wind power, which is 3 JPY/kWh (0.021 EUR/ kWh; 0.027 USD/kWh) lower than the tariff for large wind power.

Progress & Operational Details

Japan installed 169 MW of new wind power capacity in 2017. The net increase is approximately 12% smaller than that recorded in 2016, when 195 MW were installed. Cumulative wind power capacity reached 3,399 MW across 2,225 turbines at the end of the year (Figure 1). Electrical energy output from wind-based sources during 2017 totaled approximately 5.8 TWh—0.64% of the national electricity demand.

Japan's operational offshore wind power capacity reached 64.6 MW in 2017. The Fukushima FORWARD project started operation in March 2017 with one 5-MW wind turbine built on an advanced spar-type floater (manufactured by Japan Marine United Corporation).

Although the 2012 environmental impact assessment (EIA) law continues to impact wind farm projects, the wind energy sector has begun to show signs of recovery. The EIA Law requires developers of wind power plants with more than 10 MW of capacity to conduct an EIA for each project—a process that can take about four years.



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Capacity [MW]	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	3,399
Units	427	473	673	842	1,030	1,202	1,360	1,518	1,630	1,742	1,855	1,887	1,925	1,968	2,077	2,148	2,225

Figure 1. Total installed wind power capacity and number of turbines in Japan

Matters Affecting Growth & Work to Remove Barriers

METI amended the FIT act in 2017enabling FITs to be approved in the middle of the EIA process, two to three years prior to a project's construction. This should significantly improve predictions of wind power profitability.

A mismatch between wind resource locations and electricity demand in Japan is causing grid connection problems. The country's northern areas (Hokkaido and Tohoku) have most of wind resources, but their population is small and their grid infrastructure does not have enough capacity to integrate a large number of generators.

Hokkaido Electric Power Company requires wind power developers with more than 20,000 W to stabilize output fluctuation by installing batteries or taking similar measures. In October 2016, Tohoku Electric Power Company announced that it would not accept requests for new grid connection in the northern three prefectures (Aomori, Iwate, and Akita).

Tohoku Electric Power Company also developed a grid enhancement plan to enable 2.8 GW of additional transmission capacity. Several wind farm operators agreed to share the construction costs, and construction work was put out to tender. When the bidding process closed in April 2017, approximately 344 proposals were submitted; the aggregated capacity totaled 15.45 GW—six times larger than the planned capacity—including 4.46 GW for land-based wind power and 7.86 GW for offshore wind power.

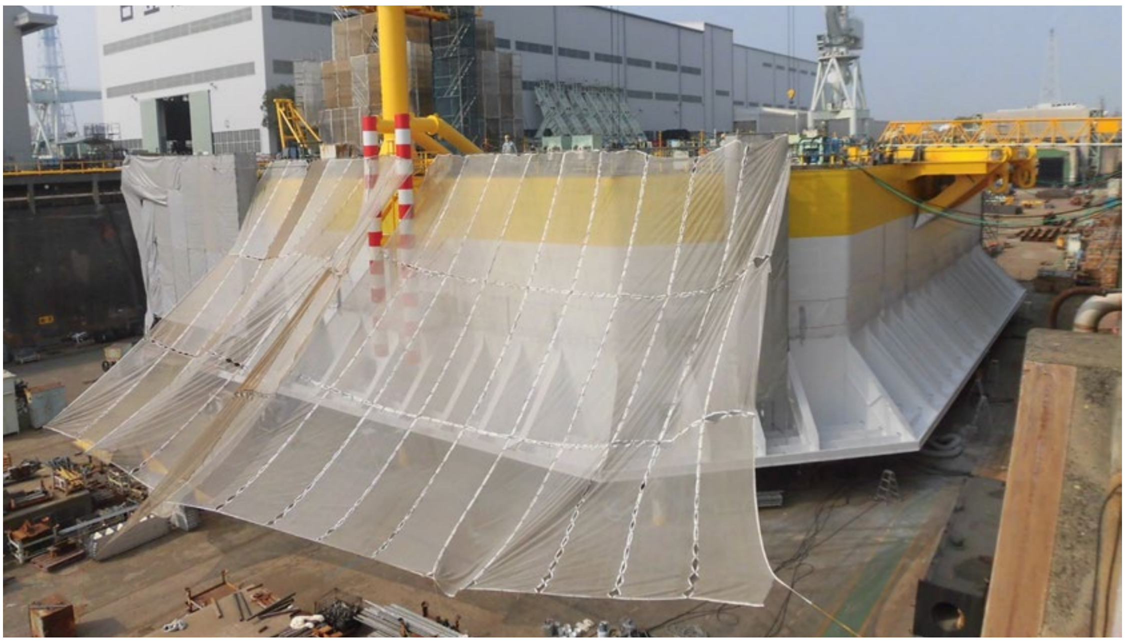


Figure 2. Offshore floater under construction at Hitachi Zosen (barge type)

National R,D&D Priorities & Budget

METI and the New Energy and Industrial Technology Development Organization (NEDO) administer the main national R&D programs in Japan. Many of these programs focus on lowering the LCOE of offshore wind. NEDO Research and Development of Offshore Wind Power Generation Technologies (FY 2008-2022) has worked on the following:

Research on Next-Generation Floating Offshore Wind Power Generation System (FY 2014-2022): To reduce the costs associated with floating offshore wind turbine system, an empirical study has been conducted to determine the potential for floating offshore wind power capacity at water depths of 50-100 m. Construction for the floater started in 2017 at Hitachi Zosen and the system will be installed in Kitakyushu offshore (Figure 2).

Figure 3. Hitachi 5-MW floating offshore wind turbine (Fukushima FORWARD)

NEDO also started developing new element technologies for a floating offshore wind turbine system, aiming to lower the cost of energy by 20 JPY/kWh (0.15 EUR/kWh; 0.18 USD/kWh) after 2030. For this project, NEDO has developed a conceptual design for a new integrated light-weight wind turbine-tower-floater structure, as well as other activities that aim to reduce the cost of the system.

Offshore Wind Resource Map (FY 2015-2017): NEDO developed a 500-m grid resolution offshore wind resource database for areas within 20 km of the Japanese coastline. The database, which utilizes the Weather Research and Forecasting Model, became accessible to the public in March 2017. The target accuracy for the simulations is an annual bias of less than ±5% for the 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 associated with offshore wind development, such as significant wave heights, fishing rights, shipping routes, water depth, and seabed properties, are collected and stored in the database.

In FY2017, NEDO modified the Resource Map based on requests from developers. Researchers improved the accuracy of coastal shapes near high potential offshore wind areas and added information that would improve site selection for offshore wind projects (ship passages, restrictive areas by aviation, self-defense forces facilities etc.).

Low Cost Construction (FY2017): NEDO conducted feasibility studies on low cost construction methods for offshore wind. Four groups studied new engineering and foundation construction, while one group studied a new vessel for construction operations. NEDO also referred to the methods used in the Joint Industry Program when considering evaluation methods for low-cost construction.

Another national R&D program by METI and NEDO focuses on further reducing the cost of wind energy and improving capacity factor. This program, NEDO Advanced Practical Research and Development of Wind Power Generation (2013-2020), involves the following: R&D of Smart Maintenance Technologies (FY 2013-2017): As wind turbine maintenance treatments change from "break down maintenance" to "preventive maintenance," NEDO has developed technology development to analyze data from wind turbine CMS (Condition Monitoring Systems), estimate the lifetime of each component, and reduce downtime when preparing to exchange components.

R&D of Performance Evaluation of Lightning Detection Device for Wind Turbine (FY 2016-2017): To reduce wind turbine issues caused by lightning strikes and downtime, NEDO evaluated the performance of several lightning detection systems and established integrated evaluation techniques.

Through the Floating Offshore Wind Farm Demonstration Project (Fukushima FORWARD PJ, FY 2011 to FY 2016), METI initiated the world's leading offshore wind demonstration. For this project, METI installed several offshore wind turbines with various types of floaters in the Pacific Ocean, more than 20 km offshore of the Fukushima prefecture.

In the first phase of the project, METI installed a Hitachi 2-MW downwind turbine with a four-column, semisubmersible floater and a 66-kV floating offshore electrical substation with a measurement platform; this turbine began operations in 2013. In 2015, an MHI 7-MW wind turbine with a three-column, semisubmersible floater was anchored to the demonstration site and began operation. In 2016, a Hitachi 5-MW downwind turbine with an advanced spar type floater (manufactured by the Japan Marine United Corporation) was installed (Figure 3). This turbine began operations in March 2017.

Collaborative Research

In 2017, Japan joined IEA Wind TCP Task 26, Cost of Wind Energy. Japanese organizations Kyushu University and Wind Energy Institute of Tokyo (WEIT) proposed the formation of new Task on downwind turbine technologies, and the ExCo approved it as Task 40 in 2017. Japan currently participates in:

- 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 30 Offshore Code Comparison Collaboration, Continued, with Correlation (OC5)
- Task 31 WAKEBENCH: Benchmarking of Wind Farm Flow Models
- Task 32 Lidar Systems for Wind Energy Deployment
- Task 40 Downwind Turbine Technologies

Japan also participates in many maintenance teams, project teams, and working groups in IEC TC 88.

IMPACT OF WIND ENERGY

Environmental Impact

In 2017, wind-generated electricity contributed to a reduction of about 2.8 million tons of CO_2 equivalent, amounting to 0.2% of Japan's total CO_2 emissions. Japan aims to reduce greenhouse gas (GHG) emissions by 26% from their FY 2013 levels by FY 2030. Wind energy will contribute somewhat to reaching this target, but its impact will be limited.

Economic Benefits & Industry Development

Japan's wind energy industry has a limited impact on the domestic economy. Hitachi is the only domestic wind turbine manufacturer; however, some Japanese manufacturers produce essential wind turbine components and export their products to foreign companies. Local governments are hopeful that the wind power industry will have a positive impact on the local economy and create jobs, especially in construction and O&M sectors.

In 2016, Hitachi developed a 5.2-MW downwind turbine, the HTW5.2-136, which is a large-rotor diameter version of a previous model, the HTW5.0-126. By increasing the rotor diameter to 136 meters and increasing the wind-swept area on the rotor by 15%, the new turbine has made it possible to increase output in regions whose annual average wind speeds are below 7.5 m/s.

Hitachi intends to market the HTW5.2-136 to regions with relatively low wind speed along the coast of Honshu, the main island of Japan. Hitachi also plans to market another turbine, the HTW5.2-127, for areas with stronger winds. These areas include the coasts of Hokkaido, the northern part of the Tohoku region in Honshu, and southern Kyushu. Hitachi has optimized the setup and control programs of the HTW5.2-127, increasing its rated power over that of the previous model.

NEXT TERM

Several new wind farm projects are still in the process of completing their EIAs. These projects are expected to begin operation within four years, adding more than 16 GW to Japan's total capacity. Other planned projects still require approval for grid connection, so their operation dates remain uncertain. On the other hand, a total of 2 GW in offshore wind projects are currently under consideration. In March 2018, the Cabinet approved a draft for new rules covering general ocean areas. If these rules go into effect, they will be a positive factor for expanding offshore wind deployment in Japan.

References

Opening photo: 2-MW downwind turbines, manufactured by Hitachi and installed within the Hinode Forest (Source: Eco Power Co., Ltd.)

[1] www.meti.go.jp/english/press/2015/0716_01.html

Author: Kazuhiro Kurumi, Ministry of Economy, Trade and Industry (METI); Yuko Takubo and Yasushi Kojima, New Energy and Industrial Technology Development Organization (NEDO); and Tetsuya Kogaki, National Institute of Advanced Industrial Science and Technology (AIST), Japan.

The Republic of Korea

Table 1. Key Statistics 2017, Korea	
Total (net) installed wind power capacity	1,165 MW (estimated)
Total offshore capacity	30 MW
New wind power capacity installed	130 MW
Decommissioned capacity (in 2017)	0 MW
Total electrical energy output from wind	1.68 TWh
Wind-generated electricity as percent of national electricity demand	0.3% (2016)
Average national capacity factor	---
National wind energy R&D budget	32 mil USD; 27 mil EUR
Target	5.6 of total electric power by 2030

OVERVIEW

The Republic of Korea installed 1,035 MW of wind power capacity by the end of 2016. In 2017, that capacity increased to approximately 1,165 MW. Wind power capacity in Korea increased 21% in 2016 and another 12% in 2017. The required rate of Renewable Portfolio Standards (RPS) in 2017 was 4.0% and the sixth-year target for RPS was almost achieved.

Construction began on the first stage of a 2.5-GW offshore wind farm in the southwest coast (originally proposed in 2010). Additionally, construction of a 60-MW wind farm is still in progress following delays due to environmental issues. Environmental issues and social acceptance are barriers to Korea's wind energy deployment.

A new renewable energy deployment goal was proposed during the presidential election in 2017. A detailed deployment plan was announced in December 2017 suggesting new deployment targets and new incentive programs including RPS.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

The Korean government has focused on wind energy as a clean energy resource that could replace fossil fuels and nuclear power. Therefore, the new government has proposed an aggressive renewable energy deployment plan, through which Korea will increase renewable energy's share of the electric power system to 20% by 2030 (Figure 1). The government has announced a detailed implementation plan and prepared the supporting policies.

New installations have increased gradually, due to the relieved restrictions for site development approval and RPS restraint. The total wind power capacity in 2017 was 1,035 MW (for turbines over 200 kW).

Korea's national target is to promote renewable energy and replace 20% of total electricity consumption with renewable energy by 2030. Currently, renewable energy production deeply depends on biomass and waste energy.

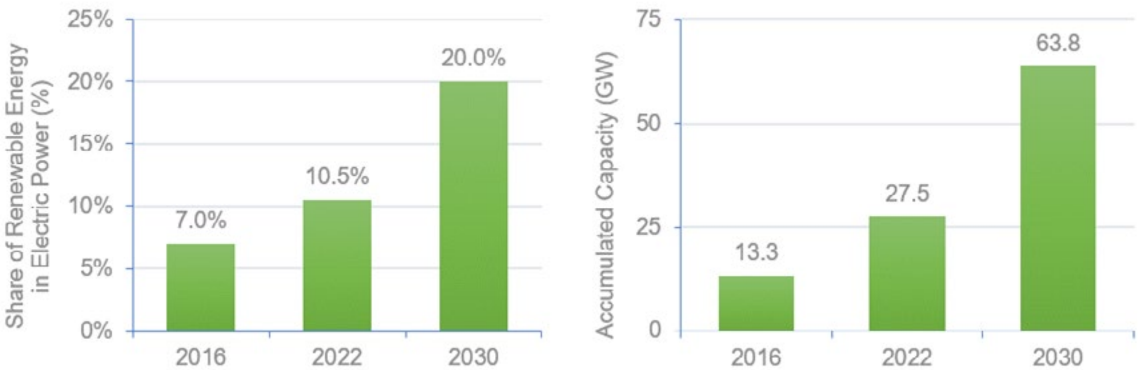


Figure 1. Target share of renewable energy in electric power (left); Target accumulated capacity (right)

Table 2. Stages for Wind Energy Technology Development in Korea by 2030

Stage	Years	Capacity	Technology
1	2017-2019	3 MW	Offshore wind turbine
2	2020-2022	5 MW	Offshore wind turbine
3	2022-2024	6-8 MW	Offshore wind turbine
4	2025-2027	Floating	Floating offshore wind turbine

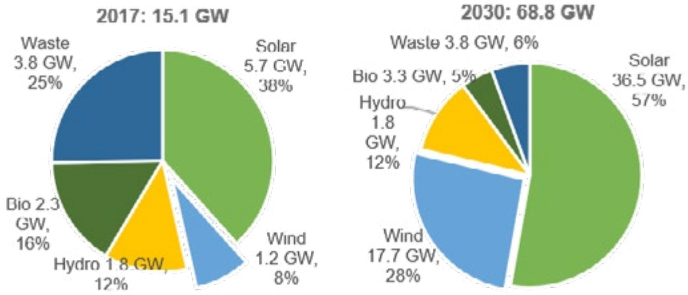


Figure 2. Korean renewable energy deployment targets, 2017 and 2030

However, because the government plans to increase shares of solar and wind energy, more than 95% of new installations will come from the solar and wind energy sectors.

Renewable energy covered 7% of Korea's electricity consumption in 2016; it is projected to increase to 10.5% by 2022 and increase again to 20% by 2030. Therefore, the renewable energy installations are expected to increase up to 27.5 GW by 2022 and 63.8 GW by 2030 (17.7 GW of which will be from wind energy). To accomplish this aggressive long-term plan, technology development for the wind energy will be performed through four stages (Table 2).

The Korean government has tried to reduce national dependency on biomass by focusing on solar and wind energy. Figure 2 shows the detailed targets for each renewable resource in the energy mix. To meet this target, 16.5 GW of wind energy should be installed by 2030.

The government subsidizes the installation of new and renewable energy (NRE) to enhance deployment and to relieve the end user's burden. The government has specially focused on school buildings, warehouses, industrial complexes, highway facilities, factories and electrical power plants. Other incentive programs are as follows:

- **Green Home Program:** In order to encourage renewable energy deployment in residential areas, the government supports the expense for installing renewable energy, including wind energy.
- **Green Building Program:** Government partially funds renewable energy installation in private buildings.
- **Provincial Government Support Program:** The central government supports any renewable energy facilities or renewable energy installations in buildings owned by a provincial government.
- **Combined Renewable Energy Support Program:** The government supports projects that install combined renewable energies (such wind and solar) on houses, public buildings, or commercial buildings.
- **Renewable Energy Requirement for Public Buildings:** New construction, expansion, or remodeling of public buildings with a floor area exceeding 1,000 m^2 must cover some of their energy use with renewables (24% in 2018).
- **Feed-in Tariff (FIT):** The standard FIT price has been adjusted annually to reflect the changing market and the economic feasibility of NRE. Wind energy has maintained a flat price of 0.1 USD/kWh (0.08 EUR/kWh) for 15 years. FITs are being applied to wind farms installed before 2012, while wind farms constructed after 2012 are supported by the RPS program.
- **RPS (Renewable Portfolio Standards):** RPS were enacted in 2012, aiming to supply more than 4% of Korea's electricity consumption with renewable resources by 2016. The regulation applies to electric power suppliers providing more than 500 MW. In 2024, the required rate will increase to 10%. The weight factors for land-based wind, offshore below 5 km, and offshore wind over 5 km are 1.0, 1.5 and 2.0, respectively. 2016 was the fifth year of RPS, and more of the requirements were fulfilled. However, imported wood pellets and waste energy have increased within the renewable energy mix. RPS rates are currently being discussed, as Korea hopes to meet 20% of electricity demand with renewables by 2030 (Table 4).

Loan & Tax Deduction, Local Government NRE Deployment Program, and others are also available as national incentive programs.

Table 3. Newly Installed Wind Capacity and Electrical Output in Korea

Year	~2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
New Capacity (MW)	132.5	79	18	108	47.3	30.9	26.6	54.5	89.8	58.6	207	182	130*	**1,165**
Electrical Output (GWh)	47*	130	239	376	436	685	817	863	913	1,148	1,146	1,683	---	**---**
*=estimate														

Table 4. Comparison of the RPS Effects with New Installation Record

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017
New Installations (MW)	35.3	33.4	51.9	72.8	91.9	61.4	207.8	186.8	130*
*=estimate									

Table 5. Korea's 2.5-GW Offshore Wind Farm Construction Plan			
	Demonstration	**Standardization**	**Deployment**
Objective	Test record set up; Track record and site design	Operation experience; Validation of comm. operation	Cost effectiveness; Site development; Comm. operation
Wind Power	60 MW	400 MW	2,000 MW
Schedule	2011-2018 (7 yrs)	2019-2020 (2 yrs)	2021-2023 (3 yrs)

Progress & Operational Details

In 2014, the Korean government relieved the restrictions for land-based wind turbine site development and simplified the approval process. This change has encouraged investment in wind energy. In 2016, Korea installed 182 MW of new wind energy capacity, a 21% increase that brought accumulated wind power slightly over 1 GW. In 2017, the country installed an estimated 130 MW.

However, most ship building and heavy industry companies have closed their businesses because of slow technology development and severe competition. Among domestic turbine suppliers, only Doosan heavy industry, Unison, and Hanjin continue to manufacture wind turbines.

On the southwest coast of the Korean peninsula, construction is progressing on a 2.5-GW offshore wind farm. As the first stage, 60-MW wind power capcity is being installed, which consists of 20 3-MW turbines (supplied by Doosan). The second stage of construction is being planned. The generation system, towers, and components account for most of the net sales in Korea's wind industry. However, sales in 2016 were down 20% from the previous year. Generation systems suffered the most serious decrease.

The number of manufacturers was also decreased in 2016. The number of companies involved in wind energy shifted from 34 in 2014 to 37 in 2015, before dropping to 30 in 2016. The wind sector employed an estimated 2,424 Koreans in 2014 and 2,369 in 2015; this decreased further to 1,813 in 2016. Complicated wind farm constructions were a large contributor to this decline in sales, number of companies, and employees.

Matters Affecting Growth & Work to Remove Barriers

The government promised that renewable energy would cover 20% of electric power generation by 2030 and issued a detailed plan in December 2017. According to the plan, Korea's cumulative wind energy capacity should be 17.7 GW by 2030; 16.4 GW of this capacity will be newly installed. Korea expects an aggressive and epochal renewable energy policy.

Two additional items escalate 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 government's revised roadmap, this wind farm will be constructed through three stages with a total budget estimated at 7.5 billion USD (6.25 billion EUR) (Table 5).

The other item is the RPS program originally started in 2012. Major electrical power suppliers are required to meet some amount of electricity demand with renewable energy (including wind power). The rate will increase to 10% in 2024.

This regulation provoked power suppliers to invest in wind energy deployment. Table 4 shows its favorable effect—namely, that new installation has doubled since 2012.
In Korea, most high mountains were categorized as strictly preserved areas, so it was very difficult to get approval for new wind farm construction. Korean fishing industry also oppose offshore wind farm construction. To achieve drastic wind energy deployment, social acceptance issues should be solved.

Figure 3. Hwasun Wind Farm, Republic of Korea (Source: Unison Co., LTD)

Table 6. Total Sales of the Wind Energy Industry in Korea										
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total Sales million USD (million EUR)	526 (438)	1,099 (916)	912 (760)	826 (688)	826 (714)	1,085 (904)	852 (710)	943 (786)	1,068 (890)	853 (711)
Growth Rate (%)	---	108	-18	-10	3	26	-22	10	13	-20

Table 7. Number of Employees for Wind Energy Industry										
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Turbine System	236	312	727	957	1,021	1,000	1,112	1,159	899	676
Casting Components	925	1,193	1,163	1,032	810	431	347	396	461	431
Total	**1,434**	**1,860**	**2,332**	**2,554**	**2,456**	**2,030**	**1,988**	**2,424**	**2,369**	**1,813**

R,D&D ACTIVITIES

National R, D&D Priorities & Budget

Investment in the wind energy industry has been falling continuously after a peak in 2009. However, the Korean government still maintains strong willingness to support wind energy, and has continuously funded wind energy R&D, although funding amounts fluctuate.

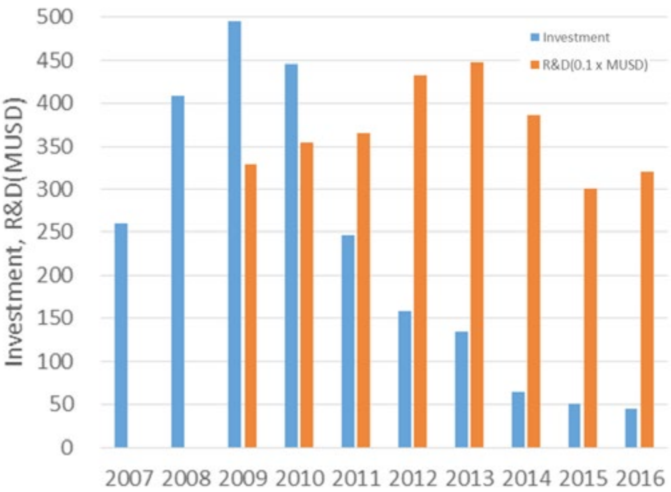


Figure 4. Total investment on the wind energy industry R&D: 0.1 million USD (0.083 million EUR)

IMPACT OF WIND ENERGY

Economic Benefits & Industry Development

The wind energy industry has a very limited impact on the Korean economy. In 2016, production yielded 853 million USD (711 million EUR) in net sales and provided 1,813 jobs.

Major shipbuilding and heavy industry companies have closed their businesses; Doosan heavy industry and Unison Inc. continue development but have downsized. Costs for Korean manufacturers are still high and not competitive to the foreign suppliers. However, Doosan is developing 3-MW turbines for the offshore wind farm. Unison developed a wind turbine suitable to the Korean atmosphere, which is characterized by low wind speeds. Unison's 2.5-MW turbine was developed with two different tower heights and longer blades.

Newly installed wind turbines, especially those supplied by the domestic manufacturers, are not operating for commercial purposes, but for system checks and accumulating track records. There is not enough electrical output on record, and it is still difficult to estimate Korea's real wind energy cost.

NEXT TERM

The optimistic vision for wind energy has been dampened by bad wind conditions, a shortage of land, strong environmentalists, and opposition from local communities and the government. Technology development has also been slower than expected, and the Korean industry is not ready to compete with foreign companies. However, the RPS program provides a motivation for renewable energy investment, and the plan to provide 20% of electricity consumption through renewables by 2030 will support the Korean wind energy deployment for the time being.

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 Agency, Korea.

México

Table 1. Key Statistics 2017, México	
Total (net) installed wind power capacity	3,942 MW
Total offshore capacity	0 MW
New wind power capacity installed	415 MW
Decommissioned capacity (in 2017)	0 MW
Total electrical energy output from wind	11.23 TWh
Wind-generated electricity as percent of national electricity demand	3.60%
Average national capacity factor	32.5%
National wind energy R&D budget	2.01 mil USD; 1.93 mil EUR
Target	12.8 GW in 2020

OVERVIEW

Due to the policies and legal framework of México's energy reform and wind power market evolution, by the end of June 2017 the country had added 415.22 MW of new wind power to the national electricity grid, bringing the total capacity to 3,942 MW. This represents about 5.32% of total installed capacity [1].

México's R&D focus is on small and medium-size turbines. These efforts range from development of a 1.2-MW scale wind turbine to installation and testing of a 2-MW horizontal wind turbine with a 100-m concrete tower, as well as innovations in automatized blade manufacturing, virtual reality for O&M staff training, and smart blade concepts for load control.

The Mexican Wind Energy Innovation Center (CEMIE-Eólico) focuses on increasing and consolidating the country's scientific and technical capacities in the field of wind energy. In 2017, CEMIE Eólico hosted the IEA Wind Technology Collaboration Programme (TCP) Executive Committee meeting in Huatulco, México. The meeting focused on national R&D efforts and included presentations from 14 member countries and 16 research Tasks. Additionally, the Instituto Nacional de Electricidad y Energías Limpias INEEL) which leads the CEMIE Eólico, hosted the second phase of the Topical Expert Meeting #89 on the Grand Vision for Wind Energy corresponding to TASK 11 Base Technology Information Exchange, and Task 25 Power Systems with Large Amounts of Wind Power.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

México's wind power industry aims to install 12.8 GW of wind power capacity by the end of 2020, and 15 GW by the end of 2022. Despite the fact that auction mechanisms allow the development of wind power at competitive prices, data shows that reaching these targets may present a challenge.

Clean energy targets, including renewables, for total electricity generation in México are 25% by 2018, 30% by 2021, 35% by 2024, 37.5% by 2040, and 50% by 2050 [1, 2]. The Energy Transition Law and the Electricity Law provide the legal framework to accelerate clean energy deployment.

México has potential wind power capacity of more than 50,000 MW but only 17,000 MW of additional installed capacity is required to reach the goal of generating 35% of electricity with clean technologies by 2024 [3]. México added 415.22 MW of new wind power to the national electricity grid by the end of June 2017, bringing the total capacity to 3,942.22 MW in 46 wind farms (Figure 1). This represents an increase of 23.46% since 2016 [1].

Public policy in renewable energies benefited substantially from the modification of the constitutional framework and the strengthening of secondary laws, which constitute the so-called "Energy Reform." In order to open new electricity markets and give legal certainty to private participation in the wind power industry, eight secondary laws were enacted as part of this reform. The institutional framework also established a variety of programs and strategies to promote the generation of energy through renewable resources.

Lastly, in order to encourage greater participation of renewable energies in the planning of the national electric sector, to diversify the energy matrix, and to reduce, under criteria of economic viability, the country's dependence on fossil fuels as a primary source of energy, two key instruments were introduced: the National Inventory of Clean Energies

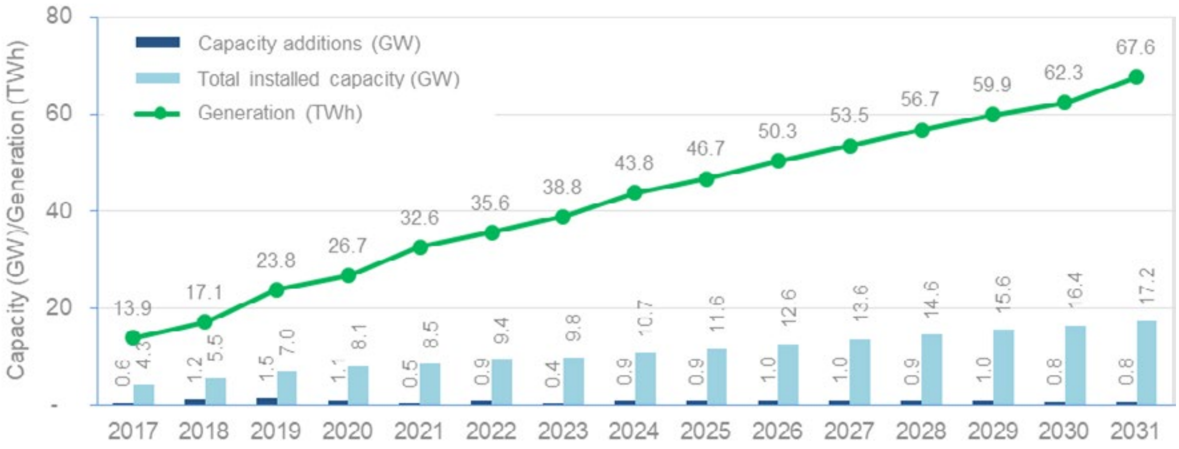


Figure 1. Projected new and cumulative capacity and wind power generation in México, 2017-2031 (Eolo Electric)

(INEEL) and the Atlas of Zones with High Potential of Clean Energies (AZEL). Additionally, a new digital platform will allow investors to request government services for installing new renewable energy projects at any time, and from any place or device [2].

Progress & Operational Details

Previously, two long-term energy auctions proved to be an effective instrument to increase penetration of wind energy. Wind power accounted for 25.7% (2,718 MW) of the total power capacity contracted via the auctions; these projects will be installed between 2017-2019.

In November 2017, the third long-term energy auction produce the following key outcomes [4]:

- Participation of "qualified services providers" (unlike the two previous auctions in which only "basic services providers" participated)
- 15 awarded projects comprising 2,012 MW of renewable energy
- Five wind projects constitute 44.65% (689 MW)
- Nine solar projects account for 55.35% (1,323 MW)
- Renewable energy traded in the third auction equals 1.78% of the total annual energy generated in México.
- Price for the clean energy (MWh + Clean Energy Certificate) was 20.57 USD/MWh (17.14 EUR/MWh)

According to the *2018 Report for Global Trends in Renewable Energy Investment*, México's market experienced the highest percent growth of new investments in renewable energies in 2017. New investments totaled 3.3 billion USD (2.75 billion EUR)–an 810% increase in funding from 2016 [5].

Matters Affecting Growth & Work to Remove Barriers

According to the *2017 Technology Road Map,* the following barriers to deployment of wind power have been identified [6]:

- Lack of regulations for negotiating land lease contracts.
- Inefficiency in the management process for obtaining permits, authorizations, and licenses at the federal, state and municipal levels.
- High dependence on foreigners for the supply of wind power industry inputs.
- Lack of specialized personnel to participate in substantive processes of developing wind power plants.
- Lack of guidelines for conducting social impact assessments.

R,D&D ACTIVITIES

National R,D&D Priorities & Budget

The Technology Roadmap, published in 2017, identified technological challenges and barriers that México faces in reaching the 2030 goal for the sustainable use of land-based wind energy [6]. The report also identified enabling and strategic actions that would promote timely incorporation of technological capabilities in order to reach the 2030 installed-capacity goal.

In the short term, greater opportunities to implement technological solutions for the operation and maintenance of wind turbines are expected to increase industry profitability. In the medium and long term, it will be necessary to respond to technological challenges associated with the storage of energy and the expansion of electricity transmission and the distribution grid. By the end of 2017, the Energy Sustainability Fund (FSE) had supported the wind energy CEMIE with a total of 2.012 million USD (1.677 million EUR).

National Research Initiatives & Results

The development and strengthening of national capacities via wind-energy R&D&I were carried out by CEMIE-Eólico, a collaborative group of 33 member organizations. Of these organizations, five are public research centers, 17 are higher education institutions, seven are private companies, one is a research center abroad, two are foreign universities, and one is a government entity.

CEMIE-Eólico's work explored the following research topics: aerodynamics and aeroelasticity; medium capacity wind turbines; small wind turbines; control systems; applications of artificial intelligence and mechatronics; and training of specialized human resources. The project has allowed the acquisition of equipment, specialized computer programs, materials, instruments, and tools, among other inputs. In addition, members have attended several courses and specialized training has been carried out.

Test Facilities & Demonstration Projects

Development of two laboratories—one for the manufacture of blades and the other for blade tests for small wind turbines—continued in 2017. In addition, the installation and testing of a 2-MW horizontal wind turbine with a 100-m concrete tower continued (Figure 3).

	2016	2017
Hidroeléctrica	15,657.42 GWh	14,992.14 GWh
Nuclear	3,857.67 GWh	6,185.31 GWh
Eólica	4,745.47 GWh	5,094.43 GWh
Geotérmica	3,069.33 GWh	3,109.56 GWh
Cogeneración eficiente	2,060.12 GWh	2,275.00 GWh
Bagazo	986.58 GWh	1,201.34 GWh
Fotovoltaica	94.28 GWh	273.45 GWh
Biogás	95.02 GWh	122.72 GWh

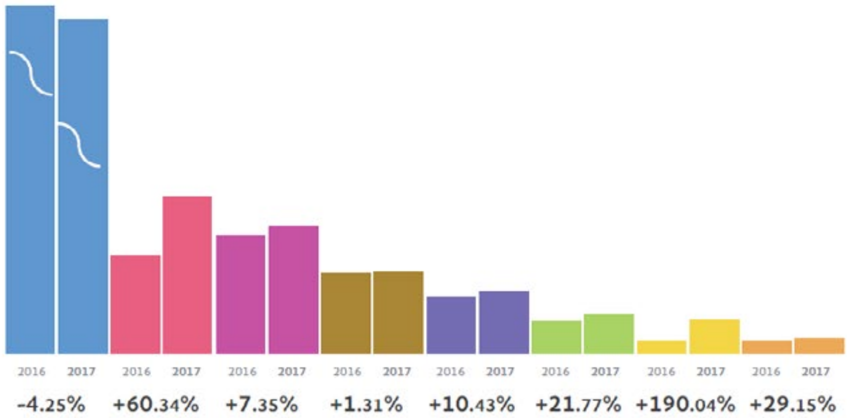


Figure 2. Growth in clean energy generation, first semester 2016-2017 (Source: SENER, Reporte De Avance De Energias Limpias Primer Semestere 2017)

Collaborative Research

In 2017, CEMIE Eólico hosted the IEA Wind Technology Collaboration Programme (TCP) Executive Committee meeting in Huatulco, México. The meeting focused on national R&D efforts and included presentations from 14 member countries and 16 research Tasks. The Instituto Nacional de Electricidad y Energías Limpias (INEEL), which leads CEMIE Eólico, hosted the second phase of the Topical Expert Meeting #89 on Grand Vision for Wind Energy corresponding to Task 11: Base Technology Information Exchange, as well as the Task 25: Power Systems with Large Amounts of Wind Power.

Figure 3. The Regional Center for Wind Technology (CERTE) in Oaxaca, México (Photo credit: © INEEL)

IMPACT OF WIND ENERGY

Environmental Impact

The development of 12,000 MW of wind power by 2020 would 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, wind technology development brings multiple economic and social benefits. Wind generated electricity supplies energy to areas that have limited access to service and encourages development in locations where large resources are located [3].

NEXT TERM

The Mexican wind industry expects to install about 1,176 MW in 2018 [2]. By 2020, the industry expects to see more than 12,000 MW installed, and up to 15,000 MW by the end of 2022 [7].

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Opening photo: Deployment of wind farms in La Ventosa, Oaxaca, México (Photo credit: © INEEL)

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Author: José Manuel Franco-Nava, National Institute of Electricity and Clean Energies (INEEL), Mexican Centre for Innovation in Wind Energy (CEMIE-Eólico), México.

The Netherlands

Table 1. Key Statistics 2017, Netherlands	
Total (net) installed wind power capacity	4.2 GW
Total offshore capacity	0.957 GW
New wind power capacity installed	0.081 GW
Decommissioned capacity (in 2017)	0.137 GW
Total electrical energy output from wind	10.58 TWh
Wind-generated electricity as percent of national electricity demand	8.8%
Average national capacity factor	28.5%
Target	14% RES by 2020

OVERVIEW

The Netherlands is making strides toward the country's renewable energy targets: 14% renewable energy sources (RES) by 2020 and 16% RES by 2023 of total energy demand.

In 2017, the new subsidy-free auction system was opened for subsidy-free applications for the Wind Farm Site I (350 MW) and II (350 MW) of Hollandse Kust Zuid. These tenders will be decided in March 2018. This system is a result of the successful previous tenders (Borssele I, II, III, and IV), where already record low prices for offshore wind energy have been realized.

This means that by the end of the year, 1,482 MW offshore are under construction or nearly under construction: Borssele I/II, 752 MW to be realized by Ørsted; Borssele III/IV, 732MW to be realized by Blauwwind); and the aforementioned 700 MW at Hollandse Kust Zuid.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

Since 2013, land-based targets for 2020 have been individually set per province (Table 2). On average, provinces have reached 54% 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.

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 is allowed a unique maximum base tariff, and the cheapest option is granted first.

Table 2. SDE+ Subsidies Granted in 2017

	Number of Projects	Budget (million EUR)	Power (MW)	Maximum subsidisable production (GWh)
Hydro	7	7	2	87
Land-based Wind	283	4,972	1,782	91,926
PV	8,331	5,188	4,265	60,773
Heat	111	1,326	429	31,892
Renewable Gas	13	376	68	6,477
Total	**8,745**	**11,869**	**6,546**	**191,155**

Applications can be submitted for the SDE+ throughout the year. However, applications completed earlier in the year receive a lower SDE+ subsidy (but a higher chance for grant approval). In 2017, the total SDE+ budget increased from 9.0 billion EUR (10.8 billion USD) to 12.0 billion EUR (14.4 billion USD). Two rounds of land-based SDE+ tendering were completed during the year (Table 2).

Offshore, after the earlier move from one-by-one deployment to a system of constant deployment, the Netherlands has moved this year from a tendering system with a single criterion (lowest bid), to a tendering system with a request for subsidy-free bids.

This change in methodology introduced a slight delay, but it means that the applicant can apply for the Hollandse Kust Zuid site permits while refraining from additional subsidies.

Hollandse Kust Zuid will be decided in March 2018, and applications for this tender will be ranked according six criteria:

- Criterion 1: the knowledge and experience of the parties involved (maximum score: 10)
- Criterion 2: the quality of the design for the wind farm (maximum score: 10)
- Criterion 3: the wind farm capacity (maximum score: 10)
- Criterion 4: the social costs (maximum score: 10)
- Criterion 5: the quality of the identification and analysis of the risks (maximum score: 20)
- Criterion 6: the quality of the measures to ensure cost-efficiency (maximum score: 40)

Progress & Operational Details

The numbers in installed wind capacity do not reflect the real wind energy progress being made in the Netherlands. The apparent standstill in land-based deployment does not show what is going on in the field, where in 2017 a record number of new turbines (1,810 MW) were applied for.

The scaling up of existing wind farms has led to a temporary increase in operational turbines being dismantled. Offshore, there are five 700-MW wind farms being tendered and the decisions for the tenders were being made during 2017.

The Netherlands saw a low wind index of 89% in 2017 (2016: 80%, 2015: 102%, 2014: 89%). This low "windex" can lead to problems for owners of older wind farms, as these farms are relatively inefficient. These owners usually run out of subsidy and are therefore receiving only the market price of electricity during low-wind periods.

However, overall increased turbine performance (e.g., increased hub height, increased swept area-to-power ratio) compensated for the 2017 low wind speeds: the land-based capacity factor in 2017 was 24.0%, which is slightly above the last 10-year average capacity factor.

Offshore, the capacity factor was 44.1%. This value nearly cannot be compared to the previous 10-year average capacity factor because of the rapid technological developments in offshore wind. The 10-year series is very discontinuous because the installed capacity tripled in the last two years with the commissioning of the 600-MW Gemini wind farm.

Matters Affecting Growth & Work to Remove Barriers

Social acceptance is one of the main obstacles in the Netherlands. Often, developers underestimate the time needed for coordination with neighborhood residents, leading to delays. The SDE+ subsidy is only available for a fixed time window once it is granted, therefore delays are quite impactful.

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, height limits around airports, obstacle lighting, and legislation concerning building on/around dikes. Often, application handling is conducted at high juridical levels and takes more time than expected.

R,D&D ACTIVITIES

National R,D&D Priorities & Budget

Since 2012, R&D programs for wind energy in the Netherlands have focused only on offshore wind energy. The Top Consortia for Knowledge and Innovation (TKI Wind Offshore Wind) coordinates these programs, representing the R&D community and the industrial sector.
In 2017, one R&D tender was specifically dedicated to offshore wind with a budget of 4.7 million EUR (5.6 million USD). Nine projects have been granted. Most of these have an industrial research profile or are working closely with knowledge institutes.

Two general renewable energy programs accept land-based wind R&D projects. Altogether, 18 applications were approved totaling 13.4 million EUR subsidy (16.1 million USD):

- **Fistuca B.V.: BLUE piling:** Offshore piling test in Rotterdam Harbour and in Borssele 3 and 4, using the water hammer technique.

- **Fistuca B.V.:** Designing a full-scale wedge connection between an offshore monopole and transition piece (Figure 1).

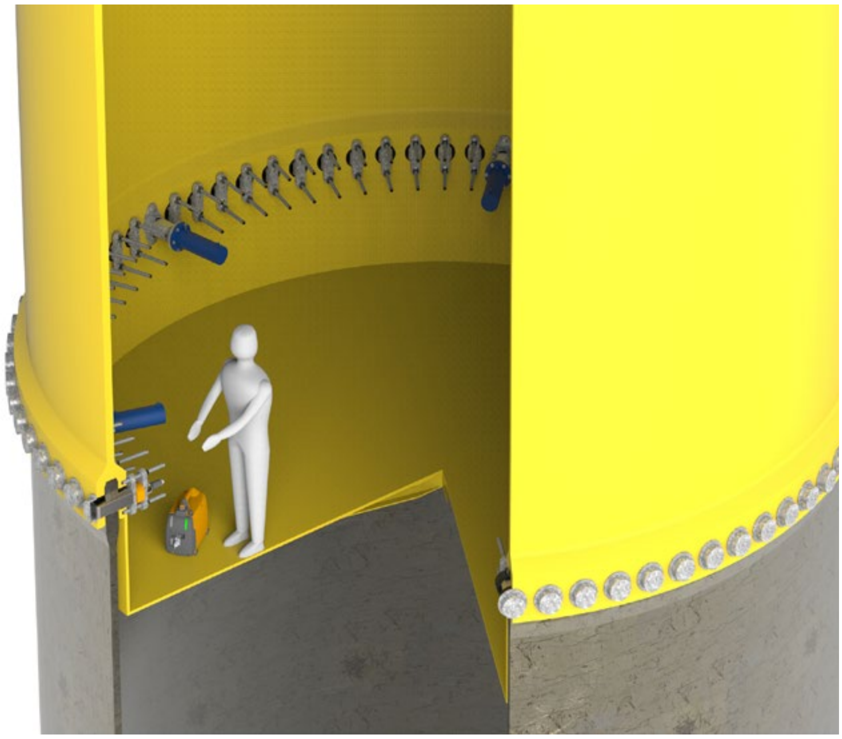

Figure 1. Impression of the Wedge connection between monopole and transition pieces (Source: Fistuca BV)

- **ECN Dutch Offshore Wind Atlas (DOWA):** A significantly more accurate version of the current offshore wind atlas, including long-term climatology and wind-field information aiming specifically at wind energy. The atlas will have a vertical range up to a height of 600 meters and can therefore be useful for the airborne wind-energy sector.

- **Marineobjects:** Operational Decision Support: Development of a system helping the vessel management team to take the right weather-related decisions for the planning or execution of offshore work.

- **DOT:** Modular Drive Train: Development of a 500-kW modular slow rotating hydraulic seawater pump to replace the classic nacelle generator, which can have multiple configurations with the option of multiple 500-kW outputs.

- **Plaxis BV:** Development of an advanced monopile design tool, using the PISA (Pile Soil Analyses) data in the finite element software package, making it possible to develop better optimized and more reliable monopiles.

- **GROW Gentle driving of piles:** Experimenting and modeling with multiple frequency monopole pile driving.

Figure 2. Scale model of the composite light weight tower (Source: Jules Dock Development BV)

- **Whiffle B.V.:** HighRes Atmosphere-Sea Modeling using GPUs to a resolution of 10 sec. and 50 m (horizontally).

- **ECN:** Modeling the appearance of Large Offshore Wind Harmonics in the grid and the mitigation of it.

- **Microbial Analysis B.V.:** Development of a Microbial Influenced Corrosion (MIC) prediction tool giving an estimation of the material loss due to MIC.

- **Marin Cable JIP:** Proving the feasibility of high-voltage power interarray cable (umbilical) for a tension leg platform floater.

- **ECN:** Vortex-wake models in wind-turbine design: Linking vortex-wake models to the certification of load calculations.

- **ECN:** Wind-turbine brain: Development of a self-learning controller using artificial intelligence.

- **Marin:** Offshore maintenance JIP II: Development of the Meteo Dashboard to a tool for short-term decisions on access to offshore wind farms.

- **Temporary Works Design B.V.:** The engineering of a motion compensated monopile Gripper (MCPG), enabling the installation of a monopole from floating vessels. The installation method will be demonstrated and validated with scale model tests in a laboratory environment.

- **Jules Dock Development B.V.:** Integral design of a lightweight tower made of composites (Figure 2).

- **Offshore Wind Logistics B.V.:** The development of a stabilized special purpose ship, featured with a 3D motion compensated lift system.

- **Mammoet Holding B.V.:** Demonstration of the Wind Turbine Maintenance Crane, which anchors itself to the tower of a wind turbine, reducing the costs of maintenance and repair of turbines (Figure 3).

Collaborative Research

In 2017, the Netherlands participated in 11 of the 15 running IEA Wind TCP Tasks, with no changes compared to 2016.

Figure 3. Impression of the self-anchoring maintenance crane. (Source: Mammoet Holding BV)

IMPACT OF WIND ENERGY

Economic Benefits & Industry Development

Emergya Wind Technologies (EWT) is installing wind turbines in the submegawatt class. After delivering its first turbine to Turkey in 2016, EWT installed its first turbine in Denmark at the end of 2017. To guarantee blade production, the company has decided to open a new factory in the eastern Netherlands.

Modular Steel Towers will build a new factory in Eemshaven for wind turbine towers. It is estimated the plant will create more than 80 full time equivalent (FTE) positions.

2B Energy will produce its 2nd and 3rd two-bladed, 6-MW, offshore wind turbines, which will be placed in the Forthwind Offshore Wind Demonstration Farm near Edinburgh, United Kingdom. Each of the turbines will be mounted on jacketed foundations with lattice towers.

As with deployment and in industrial development, the wind sector is seriously being hindered by the lack of technical personnel. It is expected that in the next ten years, more that 10,000 new jobs will be created and that the high schools and universities will be unable to supply this inflow to this sector.

NEXT TERM

The SDE+ budget is expected to be constant at 12.0 billion EUR (14.4 billion USD). In addition, the next tender in the series of five tenders for 700-MW offshore wind projects is expected to open during the fourth quarter of 2018. This tender will be second in the "Hollandse Kust" zone. Finally, in the first quarter of 2018, the tender for the Innovation Site (Borssele V, 20 MW) will open. It is expected it will be awarded in the early spring of 2018.

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Opening photo: Artist impression of the Motion Compensated Pile Gripper (Photo credit: TWD BV)

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Author: Andre de Boer, Rijksdienst Voor Ondernemend (RVO), the Netherlands.

Norway

Table 1. Key Statistics 2017, Norway	
Total (net) installed wind power capacity	1,188 MW
Total offshore capacity	2 MW
New wind power capacity installed	324 MW
Decommissioned capacity (in 2017)	9 MW
Total electrical energy output from wind	2.85 TWh
Wind-generated electricity as percent of national electricity demand	2.1%
Average national capacity factor	32.6%
National wind energy R&D budget	7.3 mil USD; 6.1 mil EUR

OVERVIEW

2017 was a record year for wind power deployment in Norway, with 324 MW of new wind power installed and an additional 1,600 MW under construction at the end of the year. Total installed capacity was 1,188 MW at the end of the year, and wind-generated electricity production totaled 2.850 TWh, compared to 2.125 TWh in 2016.

Wind resources in 2017 were slightly better than normal, with a wind index for Norwegian wind farms of 101%, corresponding to a production index of 102%. The average capacity factor for Norwegian wind farms in normal operation was 33%. Wind-generated electricity amounted to 1.9% of the country's total electricity production and offset 2.1% of total demand.

Electricity generation in Norway comes from a very high share of renewables. The primary source of electricity is hydropower, which accounted for approximately 96% of the country's electricity production in 2017 and exceeded demand by 8.9 TWh. The key statistics for 2017 are shown in Table 1.

MARKET DEVELOPMENT

The total electricity production in Norway in 2017 was 149.3 TWh. Renewable sources amounted to 97.7% of the national electricity production, 2.1% of which came from wind power. With the annual electricity consumption in the country totaling 134.1 TWh, there was a net electricity export of 15.2 TWh.

The high ratio of renewable energy production, combined with concerns about the environmental impacts of wind power development, has fueled considerable public debate on the topic of Norway's wind power development in Norway in recent years.

As a member of the European Economic Area (EEA), Norway was obliged to accept the EU's renewable energy directive in 2011. The country's renewable energy target was set to 67.5% of total energy consumption by 2020, which will be met through a combination of energy efficiency measures and increased renewable energy production.

National Targets & Policies Supporting Development

Since 2012, Norway has employed a joint electricity certificate market/scheme with Sweden to finance 28.4 TWh/yr of new renewable energy production by 2020. Of this 28.4 TWh, 13.2 TWh is to be financed by Norwegian power consumers.

This market-based electricity certificate scheme is unique in that the targets are both country- and technology- neutral, meaning that the policy does not dictate which country the new renewable energy production comes from, nor does it dictate the generation technology. Rather, the policy allows the market to dictate which type of renewable energy production is used and from where, ensuring a cost-effective increase in renewable energy production from a macroeconomic standpoint.

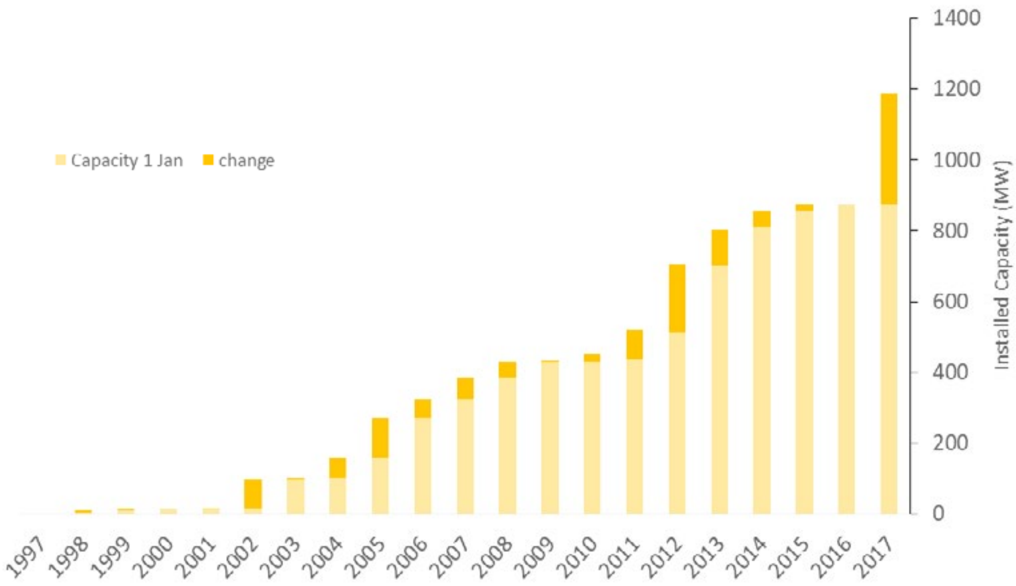

Figure 1. Development of installed capacity in Norway, 1997-2017

In practice, this means that Norway has no explicit wind energy target. However, the electricity certificate scheme has resulted in investment decisions for considerable new wind energy installations in Norway to be built by 2020.

Prior to this arrangement, financial support for wind power projects in Norway was provided by the state-owned organization Enova SF on a case-by-case basis with the goal to support projects just enough to make them commercially viable. This program ran from 2001 to 2010 and was terminated in 2011, although the last projects to receive support were commissioned in 2012 and 2013.

A key aspect of the current certificate system is that it shifts the cost of supporting renewables from Enova to the electricity consumer. Approved power plants receive one certificate for every MWh generated from renewable energy sources for 15 years from commissioning. Hence, owners of approved plants have two products on the market—electricity and certificates—and these can be sold independently of each other.

The act requires that all electricity users purchase certificates equivalent to a certain proportion of their electricity use, known as their quota obligation, which drives demand for certificates. The price of certificates is determined in the market by supply and demand, and it can vary from one transaction to another.

In April 2017, the Norwegian and Swedish governments reached an agreement about the future of the electricity certificate scheme. Norway will not expand its targets beyond the existing goal to finance 13.2 TWh of new renewable energy by the original cut off for deployment in 2020.

However, the agreement extended the cut-off for Norwegian projects by one year, meaning that 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, so Norway's wind power will have to be solely profitable through electricity sales.

Sweden has elected to expand its renewable target within the electricity certificate scheme, adding 18 TWh of new renewable production by 2030. Norway and Sweden will continue to trade certificates in a common market, even after Norwegian plants are ineligible for the scheme at the end of 2021. Due to the new target in Sweden, the demand and market for certificates will be extended until 2045.

Progress & Operational Details

Enova SF supported the development of over 700 MW of wind power commissioned between 2001 and 2013. Wind power deployment in the first years of the electricity certificate scheme has been modest, with 444 MW of wind power approved by the end of 2017. Figure 1 shows the history of wind power deployment in Norway from 1997-2017.

Norway entered into the electricity certificate scheme with Sweden in 2012, and as of the end of 2017 11 wind power plants had been approved for the scheme, totaling 529 MW. However, investment decisions for Norwegian wind power plants within the electricity certificate scheme increased dramatically in 2016 and 2017. By the end of 2017, over 1,600 MW of wind power capacity was under construction in Norway, with investment decisions made for nearly 400 MW of additional capacity to be built by 2020.

In 2017, annual wind speeds were fairly normal at all Norwegian wind farms, resulting in a national wind index of 102%. The capacity factor for operational wind farms varied between 14% and 48%; the generation-weighted average capacity factor was 33% for the year. The technical availability of new wind turbines in Norway usually ranges between 95% and 99%. Annual energy per swept area ranged from 451–2,131 kWh/m^2, with a national average of 1,216 kWh/m^2.

R,D&D ACTIVITIES

The Research Council of Norway administers a public research program for sustainable energy, ENERGIX. This program covers renewable energy, energy efficiency, energy systems, and sustainable transport (hydrogen, fuel cells, biofuels, and batteries). Industry, research institutes, and universities may receive funding for their research based upon proposals to regular calls.

Enova, the Norwegian energy agency, 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 is limited. Innovation Norway runs a program supporting prototypes within environmental-friendly technology, including wind energy. Projects are supported up to 45% of eligible costs.

In Norway, there are two research centers for offshore wind energy: the Research Center for Offshore Wind Technology (NOWITECH) at SINTEF Energy Research and the Norwegian Center for Offshore Wind Energy (NORCOWE) at Christian Michelsen Research. Another center, the Center for Environmental Design of Renewable Energy (CEDREN), conducts research on environmental issues within wind energy and other renewable energy production.

These centers receive half of their funding from the Research Council of Norway; the remainder is jointly funded by industry and the research institutions. NORCOWE and NOWITECH were established in 2009 with funding for eight years. Public funding officially ended in 2017, but hopefully the centers will continue operating at their host institutions.

National R,D&D Priorities & Budget

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 support structures for 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 O&M 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 O&M and technology
- Environmental and societal issues

The 2017 budget for the ENERGIX program was 450 million NOK (46 million EUR; 55 million USD) and the same budget is expected in 2018. In December 2017, the ENERGIX program granted funding to the following wind energy R&D projects:

- WINDPLAN: Public participation in wind power: challenges and opportunities, University of Agder (researcher project)
- Engineering speed modeling of realistic fatigue for all the individual turbines in wind parks by representative pre-calculations, Institute of Energy Technology (Knowledge building project for industry)
- Wide Frequency Range Damping Solutions for Offshore Wind Turbines, Aibel AS (industrial innovation project)
- Floating installation concept for offshore wind developments, National Oilwell Varco (industrial innovation project)

In total, the Research Council granted 60 million NOK (6.1 million EUR; 7.3 million USD) to wind energy research in 2017. ENERGIX funds 13 R&D projects, with 20 industrial companies and five research institutes involved in these projects.

National Research Initiatives & Results

The two offshore wind research centers, NOWITECH and NORCOWE have had many interesting research results:

NORCOWE: The reference wind farm that is a model that uses genuine wind and wave data. Researchers from Aalborg University (AAU) and Uni Research have built a comprehensive model of a wind farm with 80 10-MW wind turbines. Wind and wave data are imported from the FINO 3 met mast in the German North Sea.

Using the model, developers may review a number of factors to optimize the wind farm during early planning. Shoreline, a spin-off company from Norcowe (UiS), models maintenance and logistics for offshore wind farms

NOWITECH: Research partner IFE has developed a simulation software (3DFloat) to perform integrated simulation of structures, wind loads, and sea loads, which reduces costs and risks. Several research partners have worked to further develop and improve the SIMA (SIMO/RIFLEX) simulation software.

SIMA is a simulation workbench for marine applications—modeling, simulation and analysis in one single, flexible, and powerful tool. Among several other uses, SIMA assists in modeling fixed and floating offshore structures in wind, waves and current. Industry partner Fugro has developed a floating lidar buoy in cooperation with NOWITECH.

Collaborative research

In 2017, Norway participated in the following IEA Wind 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 Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models
- Task 30 Offshore Code Comparison Collaboration Continuation with Correlation (OC5)
- Task 32 Lidar Systems for Wind Energy Deployment
- 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 R,D&D

IMPACT OF WIND ENERGY

Economic Benefits & Industry Development

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. Increased wind farm construction will generate engineering and construction jobs, and ultimately jobs for maintenance personnel.

Wind power production is dispersed among several energy companies, some of which are small local utilities. The largest wind power projects are operated by large national energy companies. Foreign investment is becoming increasingly common in Norwegian wind power projects, and some Norwegian companies (Fred Olsen Renewables, Statkraft, and Statoil) are also engaged in projects in foreign countries, like offshore wind in the United Kingdom. So far, there is no significant wind turbine manufacturing industry in Norway.

NEXT TERM

The next term will be dominated by the construction of large amounts of new wind power in Norway. Installed capacity is expected to reach nearly 8 GW by 2021, based on public investment decisions as of the end of 2017. Norway will not continue with Sweden in a post-2020 expansion of the electricity certificate scheme, which means Norwegian wind power built after 2020 will need to be profitable based on power sales alone.

With expectations of increasing power prices, continued reduction in wind power costs, and new foreign investors with lower required rates of return, significant wind power additions are expected in Norway in 2020 and beyond.

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Opening photo: Mehuken Wind Farm, Norway (Source: Olav Haaverstad)

Author: David E. Weir, Norwegian Water Resources and Energy Directorate, and Harald Rikheim, Research Council of Norway.

Portugal

Table 1. Key Statistics 2017, Portugal	
Total (net) installed wind power capacity	5.3 GW
Total offshore capacity	0 GW
New wind power capacity installed	0 GW
Decommissioned capacity (in 2017)	0 GW
Total electrical energy output from wind	12.3 TWh
Wind-generated electricity as percent of national electricity demand	24.0%
Average national capacity factor	26.3%
Target	Land-based: 5.3 GW; Offshore: 0.027 GW by 2020

OVERVIEW

The wind energy sector achieved a maturity status within the Portuguese power system. In 2017, Portuguese wind farms produced 12.3 TWh, meeting 24.0% of the nation's electricity demand with wind energy [1-4]. For the third consecutive year, wind energy covered more than 100% of the electricity demand during certain hours, without any technical problems reported by the Portuguese Transmission System Operator (TSO). The instantaneous and daily electricity demand met by wind energy achieved new records during the year as well: 110% and 82%, respectively.

For the first year since wind energy capacity was deployed in Portugal, no additional wind power capacity was deployed, although repowering of some wind farms has occurred to maintain the installed capacity.

The total installed wind power capacity at end of 2017 was 5,313 MW, which represents 38.6% of the total renewable operational capacity in the country [1]. A new paradigm is emerging in Portugal, with the first licensing requirements to deploy wind farm projects without feed-in tariff.

Within the scope of the ERA-NET+ NEWA collaborative project, an important experimental wind campaign in complex terrain at Perdigão site started in 2017 with European and North-American partners. Forty meteorological masts, several LiDAR systems and a radio-sounding system were used to measure wind speed and direction from near surface up to 10 km in height. This information is crucial to validate the new European Wind Atlas [5].

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

In April 2013, the government established the national renewable energy targets through the National Renewable Energy Action Plan (NREAP) 2013-2020 [6]. This action plan aims for wind power to reach an installed capacity of 5,300 MW by 2020, of which 27 MW are reserved for offshore wind. The total land-based installed wind capacity is 5,313 MW—exceeding the estimation by 271 MW. In fact, total installed capacity is already above the targets planned for 2020.

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 [6]. In 2017, Portugal also took an important step toward the NREAP offshore wind targets. The Portuguese government approved an industrial strategy designed to accelerate development in the ocean renewable energy sector, along with the corresponding action plan: Industrial Strategy for Ocean Renewable Energies (EI-ERO) [7]. The EI-ERO plan provides guidelines for using renewable energy with a special focus on floating offshore technology, due to its higher potential compared to fixed technology (40 GW versus 1.4-3.5 GW, respectively).

The Decree Law 153/2014 maintains and regulates the national incentives for micro- and mini-generation [8]. According to Ordinance 20/2017 issued in January 2017, the feed-in tariffs from 2015 will remain valid for existing installations during the statutory period [9]. In August 2017, Ordinance no. 7087/2017 was published requiring an analysis of the fixed tariff for wind energy produced by additional capacity to be installed in existing wind farms (overcapacity).

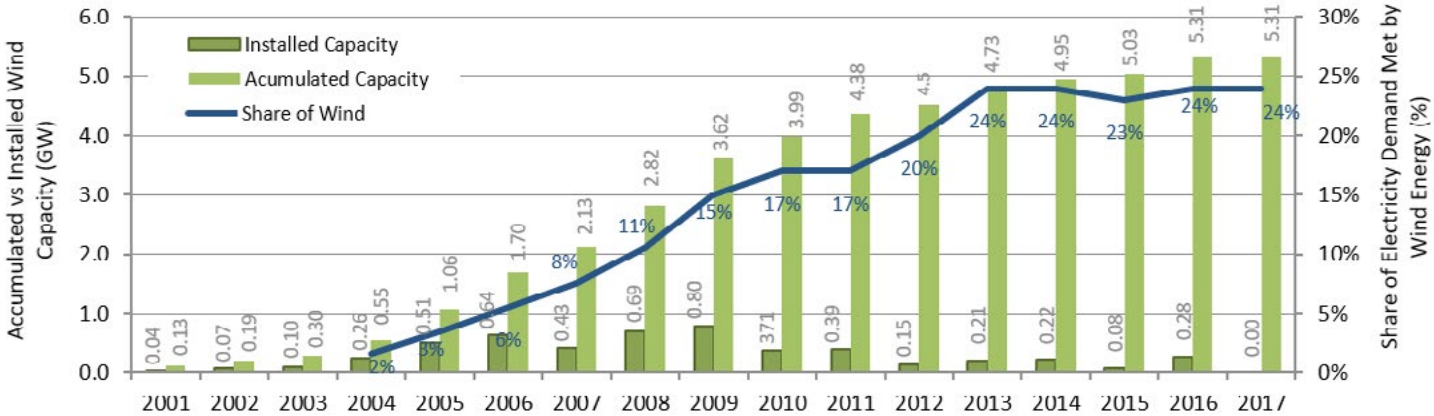

Figure 1. Installed and cumulative wind power capacities and share of electricity demand met by wind (Source: DGEG, REN, LNEG)

The current tariff is 60 EUR/MWh (72 USD/MWh). To apply this tariff, the National Regulatory Entity for Energy Services (ESRE) has to ensure any energy produced by additional capacity will not exacerbate the overall cost of the electricity [10].

Progress & Operational Details

In 2017, no additional wind power capacity was installed in Portugal (Figure 1). By the end of the year, the cumulative installed capacity was distributed over 257 wind farms, with 2,743 wind turbines operating across the country [1]. The Portuguese wind power fleet generated 12.3 TWh—24% of electricity demand—for a second consecutive year.

The wind share of the total renewable production increased 13.4% from the previous year to 50.8%. This substantial increase is due in part to the third driest year since 1931, leading to a strong decrease in the hydropower production (only 31.1% of the total renewable production during 2017) [1]. The average production at full capacity stood at 2,399 hours, indicating a 0.8% decrease since 2016 (2,419 hours).

The Portuguese TSO indicated an annual wind generation index of 0.97. This represents a 3% decrease in the index compared to 2016, which is explained by Portugal's atypical winter [2]. Figure 2 depicts the wind generation profiles on:

- The maximum demand day and the respective wind power contribution: The maximum instantaneous demand value (8,763 MW) occurred at 19:45 on 19 January 2017, but wind generation was only 2,009 MW.
- Maximum daily penetration from the wind and the daily wind: On 12 March 2017, 92.5 GWh of wind-generated electricity were supplied, accounting for 82% of the daily demand—the highest in 2017 [2].
- Instantaneous peak wind penetration: On 30 April 2017, wind power penetration was above the national consumption from 04:15 until 07:45, with the highest instantaneous penetration value (110%) at 06:15.

Both the peak wind contribution and the maximum daily penetration represent new records. The TSO did not report any technical problems during these high wind penetration events.

Matters Affecting Growth & Work to Remove Barriers

The lack of government support by suspending new grid connection capacity in 2012, combined with the low competitiveness of wind in the Iberian electricity market compared to other technologies (e.g., solar photovoltaic) has resulted in a strong divestment in the wind sector, which will likely continue in the upcoming years [11]. Nevertheless, recent governmental decisions indicate that over 123 MW of new capacity will be built in the near future [12]. This capacity is related to the 2008/2009 wind power capacity tendering procedures, which benefits from feed-in tariffs.

In 2017, the government also approved the construction of the first wind farm (with a nominal capacity of 4 MW) without feed-in tariffs or other public support. There are already 80 MW of license applications for proposed capacity without subsidies paid by consumers [13].

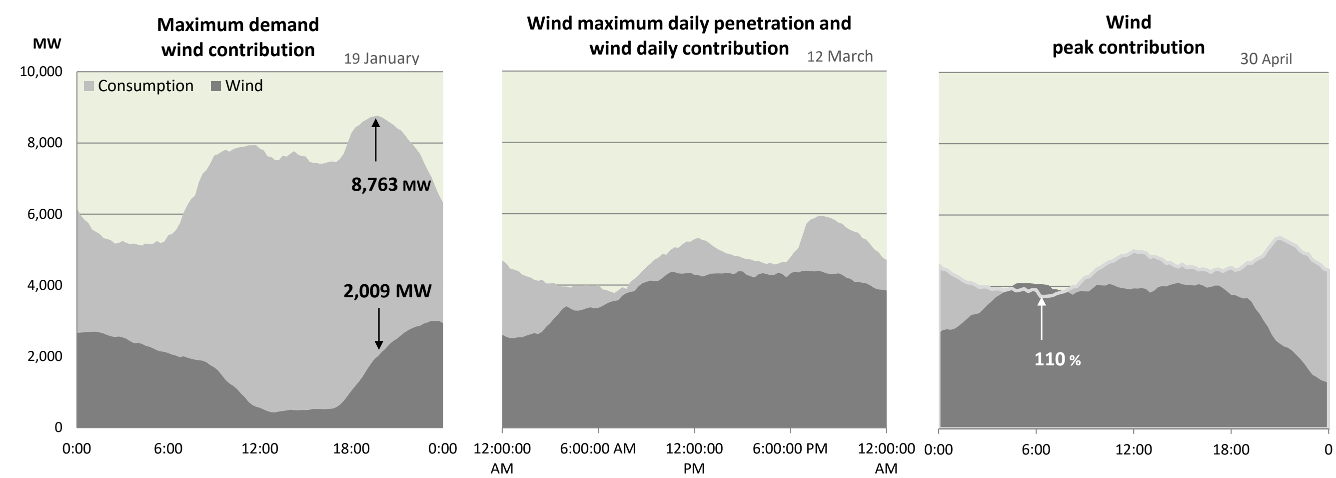

Figure 2. Wind power penetration and energy generation records during 2017 [2]

R,D&D ACTIVITIES

National R,D&D Priorities & Budget

National R&D efforts during 2017 focused on offshore wind energy, structural safe inspections, and the development of tools and methodologies to maximize the penetration of renewable energy from a grid security operation point-of-view as well as a market perspective. Most R&D activities are taking place at the main Portuguese institutes and universities being funded through national and/or European programs.

The Portuguese Foundation of Science and Technology (FCT), invested nearly 512 million EUR (614 million USD) in science and technology in 2017. Approximately 103 million EUR (123.6 million USD) was for R,D&D and innovation projects, while 55 million EUR (66 million USD) went towards scientific jobs [14]. These numbers represent a 2% increase since 2016 for both total investment and investment in R,D&D. However, the investment in scientific jobs increased 16% since 2016 [15].

National Research Initiatives & Results

A nationally-funded project, designated "Offshore Plan" (FCT program POSEUR), began in 2017. This project aims to provide optimized scenarios for planning offshore renewable energies considering the economic impacts.

Other initiatives are being developed to implement five different smart-grid facility types in Portugal, Slovakia, and Sweden to test energy delivery according to consumption, forecasting, and energy storage under the newly-launched project InteGrid [16].

The gravity foundations to support offshore wind turbines and geophysical survey campaigns are ongoing within the DEMOGRAVI3 project [17]. The first floating offshore wind park projected to be installed in 2017 is still in the pre-commercial phase, and the commission processes are expected to occur during 2018 [18].

Test Facilities & Demonstration Projects

Portugal's ongoing R&D activities are as follows:

- **InteGrid:** an H2020 demonstration project aiming to implement and test five smart-grid facility types in three countries: Portugal, Slovakia, and Sweden
- **DemoWind:** an H2020-ERA-NET collaborative demonstration and collaborative project to join offshore wind technology demonstration through 2019 under Horizon 2020
- **DEMOGRAVI3:** an H2020-funded project to demonstrate the GRAVI3 technology, an innovative gravity foundation for offshore wind turbines
- **Research Infrastructure (RI) WindScanner.PT:** constitutes the Portuguese node for the European Research Infrastructure WindScanner.EU. This project will use high precision remote sensing technology to measure the 3D wind for scientific, industrial and meteorological purposes. The RI will also include an open access platform and advanced training actions.

Collaborative Research

Portugal participates in the following IEA Wind TCP Tasks:

- Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power
- Task 30 Offshore Code Comparison Collaboration, Continued, with Correlation (OC5) (through WavEC, IST/Centec with a participation co-sponsored by EDP-Inovação)
- Task 36 Forecasting for Wind Energy (through INESC TEC, LNEG, Prewind and Smartwatt)

In addition to the IEA Wind TCP activities, Laboratório Nacional de Energia e Geologia (LNEG) is the Portuguese representative in the European Energy Research Alliance Wind Program (EERA-Wind). During 2017, LNEG also joined EERA in Energy Systems Integration (EERA – ESI). 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 focuses on facilitates the sustainable integration of wind energy into the EU grids. Portuguese partner is EDP Renewables
- **AEOLUS4FUTURE**: an H2020 project that aims to develop sustainable and efficient wind energy systems for a variety of EU needs
- **NEWA**: an ERA-NET+ project concerning the development of the new wind atlas for land-based and offshore wind in European countries
- **OceanNET**: an FP7 project to educate a new generation of engineers and scientists on floating offshore wind and wave renewable energies, which will support the emerging offshore renewable energy sector
- **LEANWIND**: an FP7 project aiming to develop innovative technical solutions to optimize offshore wind farm deployment, operation and maintenance, and decommissioning procedures.
- **FORESEE**: the IEE training project for renewables and energy efficiency in the building sector, which puts into practice the priorities identified in the Roadmap 2014–2020 under the Build Up Skills—Portugal.
- **MEDOW**: an FP7-PEOPLE project developing a new DC-grid-based, multi-terminal voltage-source converter suitable for the connection of offshore wind farms
- **SWARMs**: an H2020 project to create underwater robots in cooperation meshes to inspect offshore foundations
- **Wind-DRONE**: an H2020 project to develop a powerful UAV-based (Unmanned Aerial Vehicle) information and communication technology solution to enable safe, reliable and effective inspections of wind turbines

IMPACT OF WIND ENERGY

Environmental Impact

In 2017, wind-generated electricity generated 1.124 million EUR (1.349 million USD) for wind power plant developers. This represents a decrease of 0.5% from the previous year and a savings of 5.3 million tons of CO_2 emissions (considering a factor of 430 g/kWh) [19]. 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 generation was calculated at nearly 57.9%—a significant increase compared to 2016 (Figure 3).

Coal is the cheapest fossil fuel for generating electricity; as such, it predominately fulfils Portugal's fossil fuel dependency. Despite this, the tendency towards natural gas penetration in the power system continues to increase. Contributions from natural gas and coal resources raised the 2017 CO_2 emissions to nearly 17 million tons (MT) in mainland Portugal—a 9% increase compared to 2016 [3]. Madeira Island also observed an almost 5% increase in CO_2 emissions, reaching 0.4 MT. For the second year, Portugal's exports exceeded imports by nearly 2,684 GWh [2]. This result is particularly relevant, as the country also observed an increase in the electricity consumption to 49.6 TWh (Portugal mainland).

Economic Benefits & Industry Development

The wind industry and deployment activities in Portugal supported approximately 3,250 jobs during 2017. The mean tariff paid to the wind power plants in 2017 increased from the 2016 rate of 1.81 EUR/MWh (2.17 USD/ MWh) to 95.02 EUR/ MWh (114.02 USD/ MWh) [19]. German company Enercon continues to lead in wind power capacity deployment in Portugal, with 53.6% of the country's installed capacity. Vestas is in second place with 12.9%, followed by Gamesa (9.3%), Senvion (8.5%), Nordex (7.7%), GEWE (2.0%), Alstom (2.0%), Suzlon (1.9%), and Bonus (1.4%). Other manufacturers make up the remaining 0.6% [20].

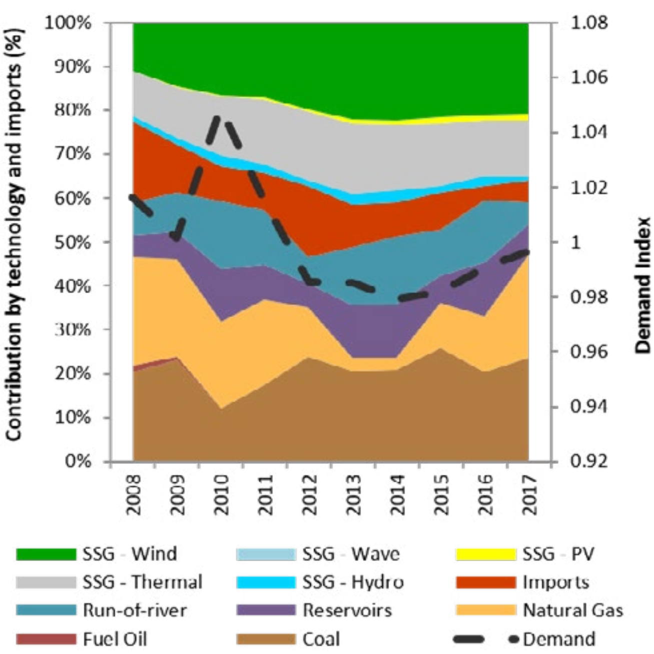

Figure 3. Yearly contribution from each technology and imports to the energy consumption and demand index from 2008-2017 in mainland Portugal (Source: REN and LNEG) [1]

NEXT TERM

With the government's commitment to support economically competitive technologies within the electricity market environment without public support, new land-based wind energy installations are expected to stagnate in the upcoming years. Thus, the first wind farm projects commissioned without feed-in tariffs will be decisive for the future of Portugal's wind energy sector. It is also expected that in the coming years, repowering will be more expressive in Portugal.

The first floating offshore wind park on the Portuguese coast (25 MW) will start implementation during 2018 with the government's support, as well as the NER300 and InnovFin programs (with support from the European Commission and the European Investment Bank, respectively).

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Spain

Table 1. Key Statistics 2017, Spain	
Total (net) installed wind power capacity	23,092 MW
Total offshore capacity	5 MW
New wind power capacity installed	96 MW
Decommissioned capacity (in 2017)	15.5 MW
Total electrical energy output from wind	47.7 TWh
Wind-generated electricity as percent of national electricity demand	18.2%
Average national capacity factor	22.1%
National wind energy R&D budget	11 mil USD; 13.2 mil EUR
Target	29.4 GW by 2020

OVERVIEW

Throughout most of 2017, wind power was the second largest source of electricity generation in Spain. But in December, wind power became the largest source with a share of 24.3%. The Energy Planning of the government, which committed to installing about 6,400 MW of new wind capacity and investing about 7.5 billion EUR (8.99 billion USD) to meet European targets for 2020, is ongoing.

The Spanish wind sector installed only 96 MW during 2017 [1]. The first auction was carried out in 2016 with 500 MW of wind power capacity allocated in contracts with no subsidy over the market price. A second auction was carried out in May 2017 with 2,979 MW of wind capacity awarded with no subsidy over the market price. The auction led to contracts for 42.53 EUR/MWh (51.03 USD/MWh). A third auction was carried out in July 2017 with 1,128 MW of wind capacity awarded with no subsidy over the market price. This auction led to contracts for 33.41 EUR (40.09 USD/kWh). The second and third auctions reached the maximum discount rate granted under the Spanish tendering process, and were established as record low prices in the European onshore wind power tender history.

National investments for wind-related R&D totaled 11 million EUR (13.2 million USD) in 2017.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

After the 2012 Spanish electricity sector reform, regulatory uncertainty led to a dramatic reduction in new projects until 2016, when the government established auctions based on investments cost discount. The target of the National Renewable Energy Action Plan (NREAP 2011-2020) was 35 GW; so far, 4.6 GW have been awarded in three subsidy-free auctions [2].

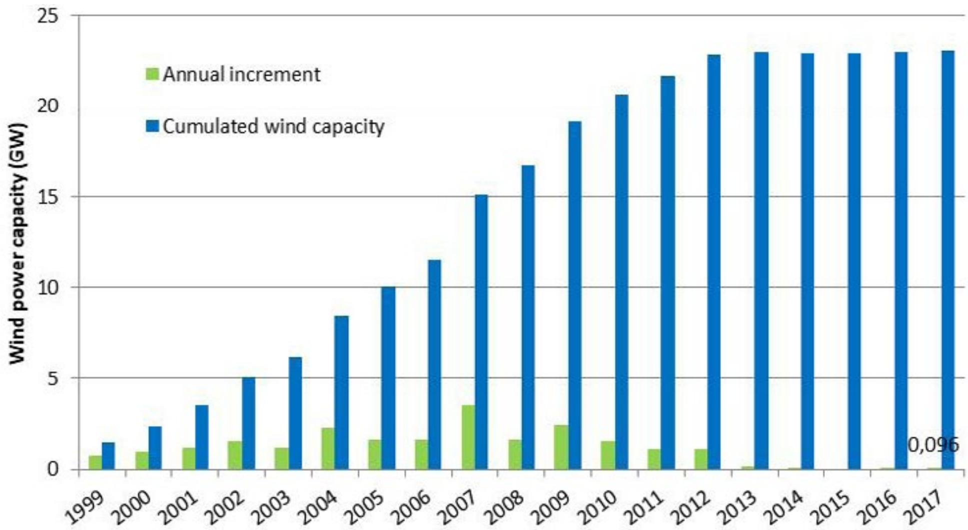
According to the Ministry of Industry Energy and Tourism's 2015 energy planning exercise, by 2020 36.6% of Spain's gross energy generation should be from renewable energy sources [3]. The most competitive technologies (wind and solar PV) will likely achieve this target, but the government's clean energy auctions will be technology-neutral.

Spain's wind power capacity forecast is 29.4 GW. To meet the national target, the country would require 6.4 GW of new wind capacity by the end of 2020, but the success of solar PV (3.91 GW) in the second auction has limited the deployment of more wind capacity. After the success of the first auction for renewable projects in 2016, with 500 MW of wind capacity awarded in subsidy-free conditions, the government decided to carry out two more auctions in 2017. Those two auctions were based on investment cost discount.

The baseline capex amounts to 1.2 million EUR/MW (1.44 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 (29.94 USD/ MWh) for the first year.

The winning bidders of the two auctions will be entitled only to the wholesale price in the spot market for the power generated, with operators accepting subsidy-free renewable power. The total wind capacity awarded is 4,607 MW. This new capacity has to be in operation by the end of December 2019.

Figure 1. Annual and cumulative installed wind power capacity in Spain (Source AEE)



Progress & Operational Details

Spain installed 96 MW of new wind power capacity in 2017. These installations included 59.1 MW in the Canary Islands, 16.45 MW for repowering in Galicia, and 20 MW of merchant subsidy-free wind farms. After the government's energy reform, only 164 MW have been installed in the last four years (Figure 1). For this reason, the Spanish wind manufacturing sector has been forced to export almost 100% of its products.

Land-based wind power capacity increased 96 MW to 23,092 MW in 2017. Wind-based electricity generation was responsible for 47.70 TWh/yr, representing 18.2% 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 2017, 4,107 MW of new wind capacity was awarded in several auctions.

The daily wind production record came on 27 December 2017, with a total wind production of 330 GWh, making wind the top technology in the Spanish power generation mix, with a 47% share of electricity demand. The maximum instantaneous share of wind energy happened on 28 February 2018 at 3:45 a.m. with a share of 60.7% of power demand.

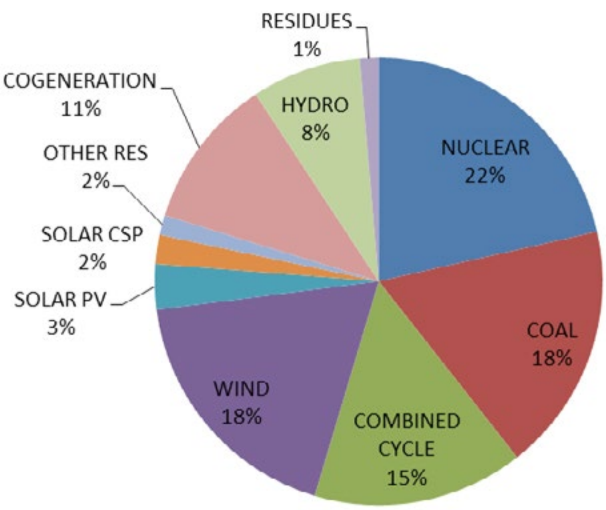


Figure 2. Sources of the 2017 power supply in Spain (Source: REE)

The Spanish wind energy sector developed only a few wind farms in 2017. A 21-year-old, 16.45-MW wind farm in the coast of Galicia was repowered in 2017, replacing 69 225-kW ECOTECNIA ECO28 turbines. The new installation—seven 2.35-MW Enercon E103 EP2 turbines—increases the energy production from 30 GWh in the previous 20 years to 34.7 GWh in the future 20 years with a 21.99 million EUR (26.39 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 ten years, with more than 3.5 GW operating 15 years or longer. In different projects in the Canary Islands, 59 MW have been installed in order to progress to the target of 45% RES share in those Islands by 2025.

The longest period of 100% penetration of RES occurred from 1 June 2017 to 9 June 2017, covering 100% of the power demand for eight days with the 12-MW Wind-Hydro System installed on El Hierro Island in the Canary Islands.

Matters Affecting Growth & Work to Remove Barriers

In one year, a total of 10,442 MW (46% of total capacity installed) of wind power capacity has already joined conventional technologies in the so-called markets and adjustment services, which are managed by the Spanish TSO (REE) and guarantee security of supply.

The first 20-MW wind farm "100% merchant" without FiT and without auction has been developed by a private company and built by SGRE in Aragon. The promotor will participate actively in the electricity market and in the adjustment services markets managed by the Spanish TSO. The annual production expected will reach between 60,000 and 70,000 MWh and will prevent the emission of 27,000 tons of CO_2 per year.

Figure 3. ELISA-ELICAN Project. 5-MW offshore wind turbine installed in Gran Canaria Island (Spain). Based on foundation gravity and with a telescopic tower, it is built of concrete and can be installed without the help of crane ships. (Photo credit: ESTEYCO)

R,D&D ACTIVITIES

National R,D&D Priorities & Budget

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 applications. National investments in wind energy R&D amounted to 11.0 million EUR (13.2 million USD) in 2017. This budget is clearly lower than in the previous years because of the delay in the calls for proposals.

National Research Initiatives & Results

During 2017, the Spanish government has been developing the new State Plan for Scientific and Technical Research and Innovation 2017–2020 [6], following the 2013–2020 Spanish Strategy for Science and Technology and Innovation, which is the reference strategic framework for the whole country for addressing research and innovation matters. This plan tries to align the R&D&I priorities with those set in the European Strategic Energy Technology Plan (SETPlan).

The new State Plan 2017–2020 is based on four programs: the State Program for the Promotion of Talent and Its Employability, the State Program for Knowledge Generation and Reinforcement of the Spanish Systems of R&D&I, the State Program for Entrepreneur Leadership on R&D&I, and the State Program for R&D&I Oriented to the Challenges to Society (addresses clean, efficient, and secure energy topics).

Regarding the types of R&D&I projects, there are projects to address research challenges, projects to address proof of concepts, projects to stimulate the collaboration between private companies and research organizations (collaborative research), projects to promote hiring young researchers, and projects to address international joint programing and national industrial research consortiums (CIEN Projects).

The R&D priorities identified by the Spanish technological platform of the wind energy sector REOLTEC are: reducing LCOE (manufacturing process, transport, installation, and O&M); improving the availability of wind farms within the scenario of a wind farm's lifetime extension; developing optimized O&M procedures for applying digitalization and big data strategies; progressing on hybrid solutions, energy storage integration, increase of the support in the operation of the power system (inertia); and reinforcing offshore wind technology, especially on floating offshore wind.

The most relevant R&D projects under development according the above-mentioned R&D priorities are:

LCOE Reduction

- **MAXWIND Project,** led by the HISPAVISTA S.L.: this project will validate and qualify the system of measurement and to calibrate the wind turbine blade pitch system.
- **WIND COMMAND Project,** led by Siemens Gamesa Renewable Energies: This project aims to develop a new generation of wind turbine and wind farm control.
- **Siemens Gamesa Renewable Energies** is also working on other R&D projects to optimize technologies and design more competitive wind turbines.
- **ARTECH Project** led by the company Norvento NED Factory S.L.: focuses on developing new technologies to adapt RES technologies to the arctic climate.

Lifetime Extension of Wind Farms

- **The NIDAROS Project** led by Ingeteam: focuses on condition monitoring systems for offshore structures.
- **The POSEIDON Project,** led by the Ingeteam: will develop a platform for the smart optimization, simulation, and evaluation of marine operations.
- The new platform for wind technology life extension called **WIND GAIN HUB,** being developed by the company Nabla Wind Power: this platform will enable small companies with complementary knowledge to join together to offer clients holistic solutions regarding, smart data and specific aeroelastic models, re-blading (ETA blades), and new sensors like iSpin (Romowind).

Optimized O&M Procedures for Wind Farms

- **SMARTIVE**, developed by the company Nabla Wind Power: this technology improves the operation, reduces O&M costs, and increases the efficiency of wind farms.
- **DIAGNOSTIC,** developed by the company NEMSolutions: focuses on monitoring (technological challenge) and diagnosis (domain and data exchange challenge).

Offshore Wind Technology

- **The U-Vessel project** led by the company Seaplace: The objective of this project is to develop an optimal vessel for transport and installation of offshore wind turbines.
- **The SCARGO Project** led by Tecnalia research center: This project is developing an innovative, cost-competitive solution for the submarine interarray cabling.
- **The EOLOS Floating LIDAR Solutions**: This project, developed by the start-up with the same name, is trying to become an enabler for lowering the cost of offshore wind. Floating LIDARS have become the trustworthy substitutes for offshore met masts. The idea is to establish a business focused on services.

Test Facilities & 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. The near-shore facility has 50-m to 90-m water depths and two 5-MW powerline connections.

Regarding new infrastructures for improving manufacturing process, the initiative called WINDBOX is an infrastructure dedicated to integrating and validating the different subsystems used in wind energy in order to optimize their design and increase their reliability.

WINDBOX is composed of nine private companies (subsystem suppliers) and one laboratory (IK4-TEKNIKER). WINDBOX includes five test benches: hydraulic pitch test, generator slipping rings test, blade and hub bearings test, yaw system test, and specific junctions test.

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: Systems Engineering Integrated R,D&D
- Task 40: Downwind wind turbines

IMPACT OF WIND ENERGY

The record of wind production was set on December 27, 2017, with a wind production of 330 GWh, making wind the first technology in the generation mix, with a 47% share of electricity demand, according to REE. December 2017 was historically the month of December with the highest wind generation and the windiest month of the year.

According to AEE reports, without this wind contribution in December, the average price of electricity could have been up to 20 EUR/MWh (24 USD/MWh) higher than that finally transferred to consumers, so the increase in wind generation has meant a saving of 30% to 35% compared to last year. In total, Spanish consumers will have saved more than 400 million EUR (480 million USD) thanks to the increased wind generation.

Environmental Impact

According to REE reports, the electrical power demand increased by 1.3% during 2017 in Spain, but the domestic power generation increased by only 0.2%. CO_2 emissions from the Spanish power generation sector increased by 18%. In 2017, 47.7 TWh of wind-generated electricity prevented approximately 11.54 million tons of CO_2, reducing the energy-related annual CO_2 emissions in Spain by 2%. Nearly 450 MW of nuclear power plants were decommissioned in 2017.

Economic Benefits & Industry Development

The Spanish wind sector employs 22,468 people annually. More than 210 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 (3.088 billion USD), in 2017. Wind Energy directly and indirectly contributes 2.731 billion EUR (3.277 billion USD) to the GDP, which represents 0.25%.

Regarding the new wind capacity under installation in Spain, most of the new wind turbines present big rotor diameters (from 114 to 136 meters) in order to increase the capacity factor as much as possible. Siemens Gamesa Renewable Energy is supplying the Model SG 3,4-132 Class IEC IIA and Model SG 2,6-114 Class IEC IA/IIA. (The new Model SG 4,2-145 Class IEC IIA will get the Type Certificate in early 2019). Other turbines frequently supplied are the model V136 3,45 Class IEC IIIA/IIB from Vestas Windpower and GE 3,4-130 Class IEC IIB from GEWind.

While Spain has installed only one 5-MW offshore wind turbine to date, there is a very active industrial offshore wind sector. Regarding ground-based offshore technology:

- Navantia shipyards are building 42 jackets for East Anglia One wind farm (United Kingdom).
- Navantia and Windar are building four jackets for the Nissum Bredning offshore wind farm (Denmark).
- ESTEYCO has started the demonstration in PLOCAN Test Facilities (Canary Islands) of the ELISA-ELICAN project, the world's first ground-based, 5-MW offshore platform with a telescopic tower configuration, allowing for both self-transportation and self-installation of the complete wind turbine (Figure 3).

Regarding floating offshore technology, the joint venture Navantia-Windar has supplied five spar-type floating foundations built for the 30MW FOWF Hywind Scotland floating wind farm. Those five floating foundations for the project were fully manufactured and assembled at Navantia's Fene yard (Galicia region).

NEXT TERM

The onshore wind energy domestic market in Spain is going to be the most exciting in Europe during the next two years. The successful auctions with a total wind capacity awarded of 4,607 MW, which have to be in operation by the end of December 2019 to confirm the future situation.

Even the progressive reduction of the cost of energy produced with onshore wind farms is allowing the promotion of viable merchant wind farms in windy areas in Spain. On the other hand, offshore wind deployment will continue to be stopped, except for some singular demo projects located in Canary Islands.

Regarding R&D activities, the delay in calls for proposals under the national R&D programs is affecting the activities. This situation is forcing more efficiency in EU calls and international agreements. It is expected that next year, with the new State Plan for Scientific and Technical Research and Innovation 2017–2020, the number of calls for proposals will increase and a greater number of innovative projects will be started.

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Opening photo: Sources of Energy (Photo credit: Juan Miguel Cervera)

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Sweden

Table 1. Key Statistics 2017, Sweden

Total (net) installed wind power capacity	6.691 GW
Total offshore capacity	0.190 GW
New wind power capacity installed	0.199 GW
Decommissioned capacity (in 2017)	0.034 GW
Total electrical energy output from wind	17.6 TWh
Wind-generated electricity as percent of national electricity demand	12.5%
Average national capacity factor	30%
National wind energy R&D budget	60 mil SEK

OVERVIEW

In 2017, Sweden installed 199 MW of new wind energy capacity (605 MW were installed in 2016). At the end of the year, the country's total installed capacity was 6,691 MW from 3,437 wind turbines.

Through the EU burden-sharing agreement. Sweden has a renewable energy goal of at least 50% of 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 the country will need to install an additional 2.5 to 6 TWh of renewable power capacity per year between 2030 and 2040 to reach that goal, and that wind power will provide a large part of it.

As Sweden's primary wind power R,D&D funding agency, the Swedish Energy Agency finances research conducted by universities and industries in several research programs. The overarching goals of wind power R,D&D is to help Sweden reach its targets and national objectives for a renewable energy system, contribute to business development, and increase jobs and exports.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

According to the EU burden-sharing agreement, Sweden is required to achieve a renewable energy share of 49% by 2020. However, Sweden 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 targets as follows:

- By 2030, Sweden's energy use should be 50% more efficient than in 2005. The target is expressed in terms of energy relatively to GDP.
- 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; thereafter, the country should achieve negative emissions.

Sweden has a technology-neutral, market-based support system for renewable electricity production called the electricity certificate. The electricity certificate scheme came into force in 2003 with the intention to increase renewable electricity production and decrease production costs. In addition, the work done in assessing areas of national interest for wind power can 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 then sell the certificates on an open market to electricity consumers.

The demand for electricity certificates is regulated by a quota, which is set in proportion to total electricity use; however, the energy-intensive industry is exempt from this requirement. The price is determined freely by the market and varies with demand and supply.

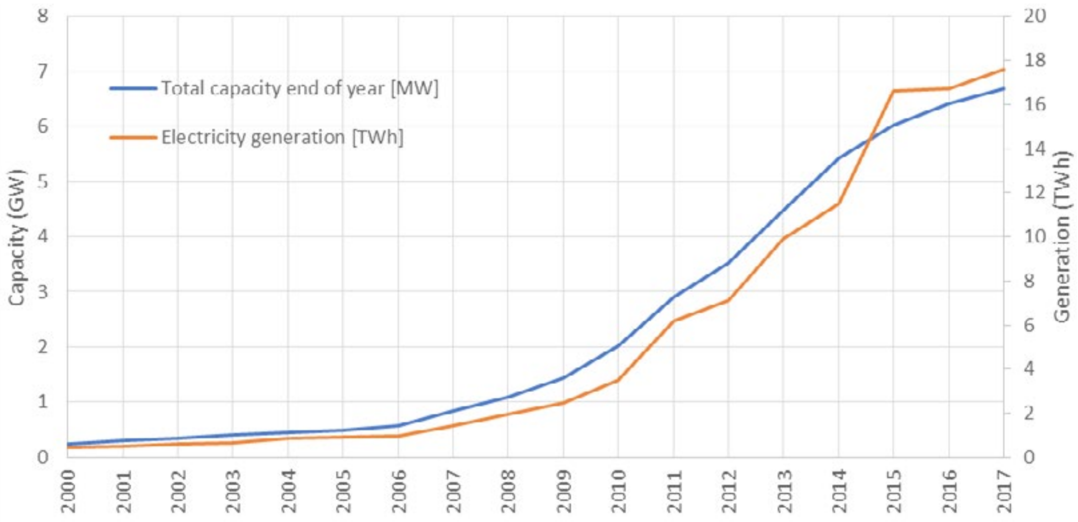

Figure 1. Installed wind power capacity in Sweden, 2000-2017

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 biopower and wind power.

Sweden and Norway have shared a common electricity certificates market since 2012, with certificates traded across borders. 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 biopower and wind power. In the 2016 Swedish energy policy agreement, the electricity certificate support scheme was extended to 2030 with the goal of an additional 18 TWh.

Progress & Operational Details

Wind energy installations in 2017 resulted in 199 MW of new capacity—significantly lower than the 605 MW installed in 2016. At the end of 2017, Sweden's total installed capacity was 6,691 MW from 3,369 wind turbines. The total electrical energy output from wind was 17.6 TWh.

Interest is gaining around Northern Sweden, as the region exhibits many areas with high potential for wind power. Turbines in these cold climate areas face several challenges not found in areas with warmer climates.

One such challenge is turbine blade icing, which leads to substantial production losses and risk for falling ice. Wind turbines in such areas must be equipped with special cold climate packages, which include tower and nacelle structures with special steel qualities and special types of oil and grease. There are also often equipped with de-icing or anti-icing equipment. However, since many challenges remain, the Swedish Energy Agency considers wind power in cold climates an R,D&D priority.

Matters Affecting Growth & Work to Remove Barriers

The expansion of wind power in Sweden is mainly driven by incentives within the electricity certificate system. Because of price erosion for both electricity and certificates in recent years, only the most profitable—and nearly exclusively land-based—sites are considered for new wind farms today.

The government has commissioned Swedish Energy Agency to investigate potential ways to eliminate grid-connection costs for offshore wind power. The Agency has chosen to examine two different models.

The first model moves the grid connection point to the offshore wind farm. This would make the Swedish national grid operator (Svenska Kraftnät) responsible for the planning, construction, and operation of the undersea connection cable, as well as all the connection costs. This measure could be funded by an increase in grid tariff.

However, the Agency believes this model would create unequal conditions for land-based wind power, as land-based wind power and other electricity production facilities would continue to pay connection costs. The Agency's also assessed that wind power producers would have no incentive to select locations that lead to cost-efficient connections if they are not obligated to pay any portion of the connection costs.

The second model provides wind power producers with subsidies to cover a portion of the connection costs. The Agency proposes that this support only cover the undersea cable and transformers, as this would create conditions more comparable to land-based wind power. In the Agency's estimation, this model would limit the total cost of removing connection costs, while still incentivizing wind power producers to choose cost-effective connection locations. The subsidies under this model would be financed by a special surcharge, which all electricity consumers would pay.

Given the framework of this assignment, the Swedish Energy Agency has not been able to conduct a more detailed analysis of the constitutional aspects of the models for removing grid-connection costs. Due to EU regulations on State aid, such an analysis would be required in order to assess each model's feasibility.

R,D&D ACTIVITIES

In 2016, the Swedish Energy Agency adopted a wind energy strategy with three prioritized areas: wind in Swedish conditions, sustainability, and integration in the energy system. Wind in Swedish conditions refers to the installation and operation of wind turbines in cold climates, forested areas, and the Baltic Sea.

The overarching aim of wind power R,D&D is to make contributions that help Sweden reach its national targets and objectives for a renewable energy system. Moreover, it should also contribute to business development in Sweden by creating jobs and increasing Swedish exports.

National R,D&D Priorities & Budget

Four research programs carried out publicly-funded wind energy research in 2017: Vindforsk, Vindval, the Swedish Wind Power Technology Centre (SWPTC), and VindEL [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 by the Swedish Energy Agency (50%) and industry (50%). Vindforsk is organized in three research topics:

- Wind resource assessment and installation
- Operation and maintenance
- Grid integration

Vindval is a knowledge program focused on studying the environmental effects of wind power. The program is financed by the Swedish Energy Agency and 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). Vindval researches 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 optimizing wind turbine design, which takes into account the interaction between all components. 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 VindEL runs from 2017-2021. It is financed by the Swedish Energy Agency and has a total budget of 133 million SEK (13 million EUR; 16 million USD). The program focuses on finding technical solutions within the three priority areas defined in Sweden's strategy for wind power:

- Wind in Swedish conditions
- Sustainability
- Integration in the energy system

National Research Initiatives & Results

Below are some of Sweden's 2017 wind energy projects:

"**Wind turbine performance decline in Sweden**" showed that wind power production is nearly constant during the first years of operation, but subsequently it begins to decline. Wind turbines constructed before 2007 lose around 0.15 capacity factor percentage points per year in absolute terms, corresponding to a lifetime energy loss of 6%. A gradual increase of downtime accounts for about one-third of the decline, while worsened efficiency accounts for the rest. This project gave recommendations for wind energy calculations for current and future projects. The recommended estimate is a decline of 0.10-0.20 pp/yr, including increased downtime and worsened efficiency. This rate of energy loss is higher than normally assumed in the wind sector today; however, compared to results from the UK, the decline is considerably smaller.

Deicing of wind turbines—continuous autonomy system for deicing of wind turbine blades aimed to develop a new and innovative method for deicing and anti-icing wind turbine blades. The project researched methods for detecting ice, as well as controlling temperature of the blade surface. The goal within the project was to develop a prototype and evaluate it on an existing wind turbine.

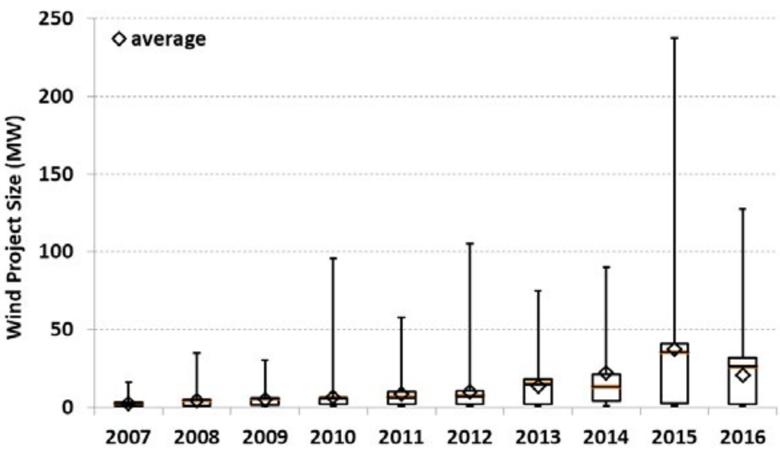

Figure 2. Installed wind power capacity in Sweden by commercial online date, 2000-2017

LoadMonitor—measuring and modeling vibrations and loads on wind turbines worked to maximize energy availability while keeping loads below reasonable limits. The project analyzed the relationship between upstream wind characteristics and nacelle vibrations, based on concurrent 3D-measurements of the upstream wind and high-resolution vibration measurements. LoadMonitor provided a combined measurement and analysis system, which measures nacelle vibrations with high resolution to detect underperformance and identify non-standard wind conditions and component failure. The knowledge and tools developed within this project will be of high relevance for turbine performance control.

Wind power in forest: fatigue and longevity used large eddy calculations (i.e. numerical accurate solutions of Navier-Stokes equations) of an atmospheric boundary layer above and in forest to measure instantaneous turbulent flow rates and calculate fatigue loads on a wind turbine. A wind turbine located in a forest area is expected to tolerate increased turbulence and windshield layers compared to wind turbines standing in an open landscape. Wind turbines and fatigue loads on the wind power plants become almost three times larger in a forest area than in an open landscape. The calculations from the project confirm this hypothesis and quantify this effect.

Test Facilities & Demonstration Projects

RISE Research Institutes of Sweden and Skellefteå Kraft are about to establish a test center in Uljabuouda, in Arjeplog. There, the global wind industry will be able to test their wind turbines and other equipment in cold and icy conditions. There were no large demonstrations initiated in 2017.

Collaborative Research

In 2017, Swedish researchers participated in EU programs (ERA-NET PLUS New European Wind Atlas), the Nordic Energy Research programs, and 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 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN)
- Task 36 Chapter 16 Forecasting for Wind Energy

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 with an active energy policy, incentives, and research funding. Currently, CO_2 emissions from electricity production are relatively low, because hydro, nuclear, bio, and wind energy are the main contributors to the energy system.

NEXT TERM

In the coming years, much of Sweden's new wind power capacity will be in forested areas and in northern Sweden; high wind potential, as estimated by Swedish wind mapping, has sparked interest in these regions. However, there is significant uncertainty surrounding the energy capture and loads of turbines in forested areas. Upcoming research projects hope to increase the knowledge of wind shear and turbulence in these areas. The research programs Vindval, VindEL, and the SWPTC will continue during 2018.

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Opening photo: Wind turbine supplying electricity to Sweden (Credit: Per Westergard)

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Switzerland

Table 1. Key Statistics 2017, Switzerland

Total (net) installed wind power capacity	75 MW
Total offshore capacity	0 MW
New wind power capacity installed	0 MW
Decommissioned capacity (in 2017)	0 MW
Total electrical energy output from wind	0.132 TWh
Wind-generated electricity as percent of national electricity demand	0.2%
National wind energy R&D budget	619,730 EUR; 763,313 USD
Target	4.3 TWh/yr

OVERVIEW

By the end of 2017, Switzerland had 37 large wind turbines in operation with a total rated power of 75 MW. These turbines produced 132 GWh of electricity. No new turbines were installed in 2017, but the 15 MW of additional capacity installed during 2016 caused a 20% increase is wind-generated electricity.

Switzerland has been utilizing a cost-covering feed-in-tariff (FIT) for renewable energy 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 3.402 TWh under the FIT scheme. 2017 was marked by the Swiss people's approval of the Energy Strategy 2050 in May, with an approval rate close to 60% [2]. This opened the door for a new legislative package in favor of renewable energies and energy efficiency at the beginning of 2018.

Research activities are internationally cross-linked, mainly in the fields of cold climates, turbulent and remote sites, and social acceptance.

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

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, wind projects with an estimated energy yield of 83.4 GWh are in operation and being supported under the scheme; additional projects with a potential energy yield of 1,727 GWh have been registered, and 1,675 GWh are on the waiting list.

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. In 2017, the levy was 11.7 EUR/MWh (14.4 USD/MWh)—the maximum accepted under current Swiss energy law. This leads to approximately 543 million CHF (453 million EUR; 557 million USD) of available funds each year, after operating costs and funds reserved for annexed programs.

The current FIT for newly installed wind turbines is between 112 and167 EUR/MWh (138-205 USD/MWh) [5]. Wind turbines built on locations 1,700 m or more above sea level receive an altitude bonus of 21 EUR/MWh (25 USD/MWh) in addition to the standard retribution.

Concurrently, the Swiss Federal Council adopted the Wind Energy Conception in 2017 [3]. This document sets how the interests of the State should be taken into consideration in the wind project planning process and indicates the areas particularly suitable for harnessing wind energy. It sets an unbinding wind energy target for each canton with wind power generation potential, which the cantonal department of energy should take into consideration in its cantonal energy plan.

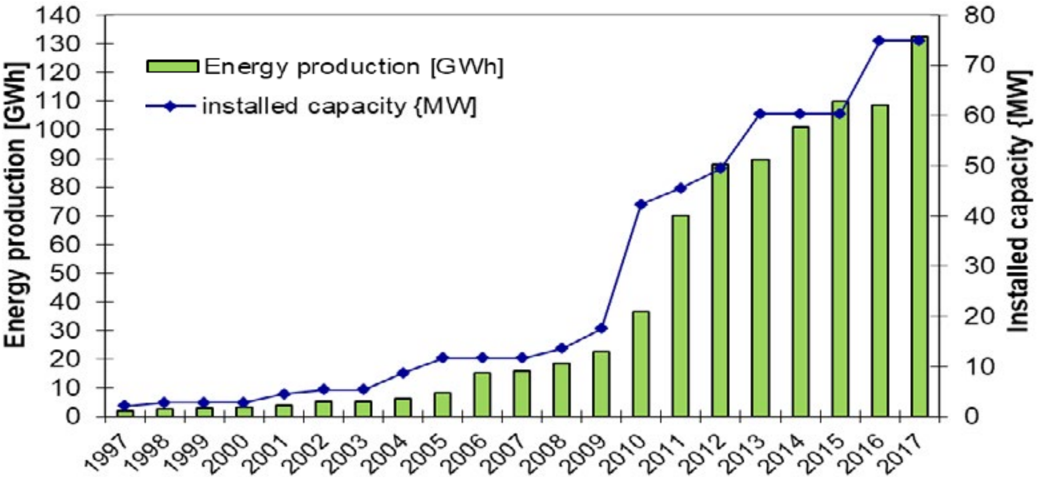

Figure 1. 20 years of wind energy power generation in Switzerland. Source: SuisseEole

Progress & Operational Details

Approximately 59% of Switzerland's overall electricity production comes from renewable sources, with hydropower as the biggest contributor by far (95%). Wind power generation currently covers 0.2% of the Swiss electricity consumption.

In 2017, no new turbines were installed. However, the 15 MW of additional capacity from 2016 (due to three new turbines and four repowerings) caused an increase in wind-generated electricity of 20% compared to 2016–132 GWh of wind-generated electricity. Future projects that are already advanced in the planning procedures represent an additional 170 MW.

Matters Affecting Growth & 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; this was confirmed by the approval of the Energy Strategy 2050. 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 should help ease planning procedures. In particular, wind farms that are expected to produce more than 20 GWh/year are now considered to be of national interest. Furthermore, the new Energy Strategy 2050 clearly defines role of the cantonal authorities in the planning procedures, so they are now able to better assist project developers and communes with a project on their territory.

R,D&D ACTIVITIES

National R,D&D Priorities & Budget

2017 marked the beginning of a new energy research term (2017-2022), with the following new priorities [4]:

- 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

In 2017, the budget for wind energy related R&D and demonstration projects was approximately 619,730 EUR (763,313 USD). The national Swiss Energy program allocated approximately 1.1 million CHF (1.0 million EUR; 1.1 million USD) to the wind energy sector for information activities, quality assurance measures, and for the support of regional and communal planning authorities [5].

National Research Initiative & Results

Wind turbine noise received special attention this year with two research projects dedicated to it. Computer models for new wind farm projects and on-site measurements for existing wind farms are often discussed by concerned authorities and organizations.

The first project sought to improve the evaluation of wind farm noise. EcoAcoustic SA compared the current Swiss calculation method with the results of in situ measurements from a specific wind park and analyzed a series of audio recordings in detail.

Comparisons between the measured results and the modeling was completed, showing that the average measured global sound level (annual averaged LAeq for daytime) is 4 dB(A) higher than modeled values (with consideration of the statistical index LA90). This discrepancy between measurement and calculated results is mainly due to the fact that measured wind turbine noise is increased by the presence of background noise (especially from wind in the vegetation). With increasing wind speeds over 7 m/s, the difference between measurement and modeling is particularly marked.

The second project aimed to mitigate the effects of wind turbine noise. Given the particular topography and the proximity to houses located in Saint-Brais (canton Jura), wind turbine noise is clearly audible even if emission limit values are respected.

Figure 2. Swiss wind farm at Mont Crosin, which produced 17 GWh more in 2017 than in 2016 following a repowering (Photo credit: Suisse Eole picture contest: Hans Peter Jost)

For this project, a system of trailing edge serrations (TES) were installed on each of the wind turbine blades in spring 2017. This helped control the blades' acoustic efficiencies, as measured in situ. The project evaluated a new method to measure wind turbine noise near wind turbines and at emission points (such as more than 500 meters away). The proposed methodology is based on continuous noise measurements with periods of start and stop for each wind turbine. This allowed researchers to validate practical issues in measuring the WTN in coherence with IEC 61400-11:2012.

A statistical analysis, based on almost all the operating conditions of the wind turbines (rpm and orientation), concluded that the average global sound level obtained from the measurements after TES integration was lower than the values obtained before, and that TES efficiency increases along with wind speed. In conclusion, the TES efficiency evaluation curve indicates a noise reduction of at least approximately 2 dB considering the collected data during this project.

Test Facilities & Demonstration Projects

The Laboratory for Energy Conversion of ETH Zurich designed a scaled-model of modern, variable-speed, variable-pitch-control, multi-megawatt turbines for its research project "Impacts of Atmospheric and Wake Turbulence on Wind Turbine Fatigue Loading." This model was representative of wind turbines installed in Switzerland, but 200x reduced, with a diameter of 60 cm instead of 120 m. The model was manufactured and installed at the ETH Zurich.

In contrast to prior works—which primarily used simulations to investigate independent pitch control—this project presents the first experimental investigation of independent pitch control with a sub-scale model wind-turbine test facility. It demonstrated that independent pitch control based on sinusoidal pitching that is locked to the phase of the rotor rotation can yield power increases between 10-16%, depending on turbine's yaw angle. The power increase occurs because sinusoidal pitching compensates for the velocity variations induced by rotor tilt—a characteristic of modern, multi-megawatt turbines.

As the successful development of the independent pitch control for the sub-scale model was a formidable challenge, the measurements with elevated turbulence were limited. Nevertheless, it was observed that with elevated turbulence the wake is asymmetric, and this asymmetry is attributed to rotation of the wake. In ongoing work, the impact of elevated turbulence on the loads will be experimentally quantified.

Collaborative Research

Switzerland is involved in the following IEA Wind TCP Tasks:

- Task 11 Base Technology Information Exchange
- Task 19 Wind Energy in Cold Climates: especially active participation of Meteotest
- 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)

IMPACT OF WIND ENERGY

Environmental Impact

Since Switzerland's electricity generation mix is nearly carbon-neutral, increasing wind-generated electricity will not contribute to carbon emission reduction targets. However, wind-generated electricity, combined with solar power, is expected to replace power from Swiss nuclear power plants, which will likely be shut down at the end of their lifetimes.

Economic Benefits & Industry Development

A study estimated that the total turnover in the Swiss wind energy sector in 2010 was about 38.9 million EUR (41.0 million USD), and that the wind industry employed about 290 people [6]. Another study from 2009 estimated that the worldwide turnover of Swiss companies in wind energy will be 8.6 billion EUR (9.1 billion USD) by 2020 [7].

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, SIKA, Huntsman, Clariant)
- Grid connection (ABB)
- Development and production of power electronics such as inverters (ABB, VonRoll)
- Services in the field of site assessments and project development (Meteotest, Interwind, NEK, New Energy Scout, Kohle/ Nussbaumer, etc.)

NEXT TERM

The impact of wind turbines on microwave link systems is another important topic in the current Swiss context. 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 result in a high probability of collocation of wind farms and microwave link systems. This issue has been addressed and a measurement project has been approved, which will start in 2018.

Furthermore, numerous wind farm projects are on hold because of avian considerations. The current approach is to study each specific wind farm project for the potential impact on all bird species (migratory or local) in the area. In 2018, the first study will take a more systemic approach to identify key areas for specific species.

Figure 3. Saint-Brais wind farm with trailing edge serrations (Photo credit: PRONA SA)

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Opening photo: Saint Brais wind farm with trailing edge serrations (Photo credit: PRONA SA)

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United Kingdom

Table 1. Key Statistics 2017, U.K.	
Total (net) installed wind power capacity	19,836 MW
Total offshore capacity	6,975 MW
New wind power capacity installed	1,681 MW
Decommissioned capacity (in 2017)	0 MW
Total electrical energy output from wind	49.61 TWh
Wind-generated electricity as percent of national electricity demand	14.2%
Average national capacity factor	28.5%
Target	10 GW offshore by 2020

OVERVIEW

The United Kingdom (UK) set a new record for land-based and offshore wind power generation in 2017. This continued upward momentum was due to increased capacity and higher wind speeds in the last quarter, compared to the low wind speeds recorded the previous year [1].

Land-based wind installations hit record highs, as developers rushed to secure subsidies before the Renewable Obligation Certificate (ROC) deadline. Offshore wind costs continued their downward trend following the results of the Contracts for Difference (CfD) Allocation Round 2 in April 2017.

The Clean Growth Strategy was released in autumn 2017, making 557 million GBP (627 million EUR; 752 million USD) available for less established technologies in the next CfD auction round. However, it was later confirmed that there will be no new subsidies for renewable energy deployments until the new scheme set to replace the Levy Control Framework (LCF) is implemented in 2025 [2].

Several R&D funds were launched last year, highlighting the UK government's will to support R&D activities as part of a wider industrial strategy, which includes the wind sector. There was significant progress with the installation of larger turbines and condition monitoring systems, as well as the development of innovative solutions in robotics, autonomous systems and artificial intelligence (AI).

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

The Clean Growth Strategy, released in October 2017, established how the UK can take a global lead in cutting carbon emissions to combat climate change while driving economic growth. This plan will invest over 2.5 billion GBP (2.8 billion EUR; 3.4 billion USD) to support low carbon innovation from 2015 to 2021. Up to 557 million GBP (627 million EUR; 752 million USD) will be allocated to CfDs for less established renewable electricity projects—mainly offshore wind—in the early 2020s [3].

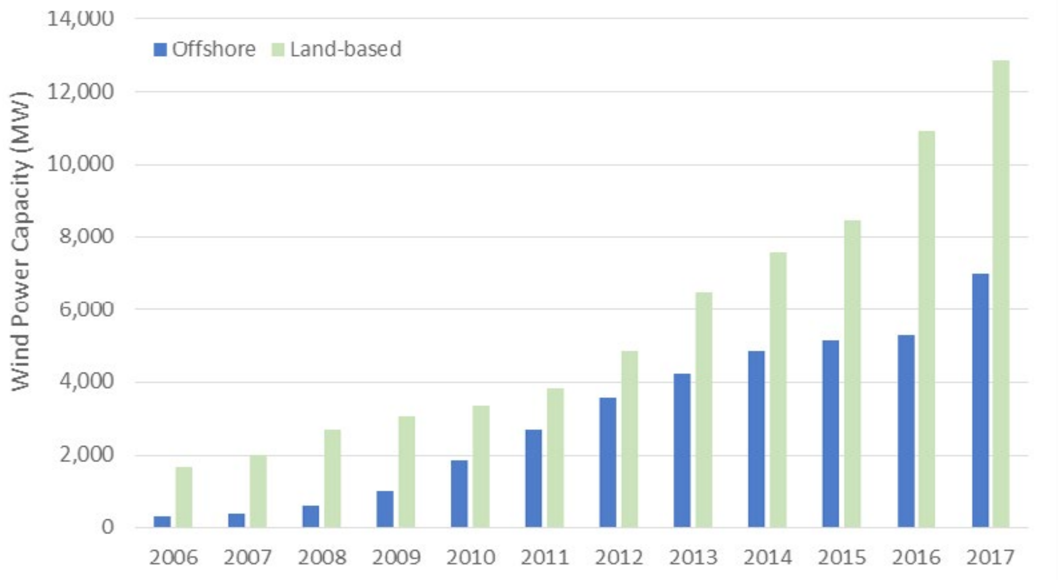
The Autumn Budget stated that there will be no new subsidies for renewable energy until 2025 [4]. The existing LCF was replaced by the Control for Low Carbon Levies framework, which provides an updated estimate for power capacity by 2025. The potential 2025 deployment is approximately 14 GW for offshore wind and 13 GW for land-based [5].

Since the closure of ROC support scheme in 2017, the UK now runs competitive CfD allocation rounds. The results of the second CfD round for less established renewable technologies were announced in September 2017; three wind farms were successful, with two of them clearing at strike prices as low as 57.5 GBP/MWh (64.7 EUR/MWh; 77.6 USD/MWh). Land-based wind was not included as an eligible technology in this round of CfDs, but the UK government has proposed new plans to enable remote wind projects to apply for the next CfD planned for spring 2019 [6].

Progress & Operational Details

Wind-generated electricity met 14.2% of the UK electricity demand, which fell from 357 TWh in 2016 to 350 TWh in 2017 [1]. This decrease was due to warmer weather and improved energy efficiency measures. Land-based capacity reached 12.8 GW in 2017, 18% higher compared to 2016 (Figure 1) [7].

Figure 1. Installed wind power capacity in the UK, 2006-2017 (Source: ORE Catapult)



Share of land-based wind energy was 8.6% of the total electricity generated, a rise of 2.4% compared to 2016 numbers [1]. Land-based wind power generation increased by 37%, to a record 28.7 TWh in a year as developers rushed to commission projects before the end of ROC scheme [1].

In 2017, the UK added 1.7 GW of offshore wind capacity, bringing the cumulative total to 7 GW. Offshore wind-generated electricity reached a record level of 20.9 TWh—27% higher than last year—due to increased capacity and higher wind speeds [1]. Share of offshore wind-generated electricity also rose by 1.4%, reaching 6.2% [1]. The average offshore wind capacity factor was estimated at 38.9% [8].

In November 2017, the 402-MW Dudgeon offshore wind farm was officially opened, with operator Statoil and its partners Masdar and Statkraft quoting construction costs 15% lower than the original 1.5 billion GBP (1.7 billion EUR; 2.0 billion USD) budget [9]. Another important milestone of the year was the commissioning of the 30-MW Hywind Scotland floating wind pilot park.

Land-based wind costs have fallen rapidly and are currently comparable to the cost of building new gas power stations [10]. EDF Energy Renewables sold its 80% stake in five land-based wind farms to Greencoat UK Wind to pursue other renewable projects in the UK [11]. SSE issued the biggest ever green bond by a UK company (600 million GBP; 675 million EUR; 810 million USD), providing capital to refinance SSE's portfolio of land-based wind farms [12].

Matters Affecting Growth & Work to Remove Barriers

The Clean Growth Strategy demonstrates the UK's commitment to ambitious clean energy policies. More detailed actions might be needed to meet the UK's legally-binding climate change targets and to increase UK clean energy investment, which fell 56% to 7.5 billion GBP (8.4 billion EUR; 10.2 billion USD) [13]. The approach adopted requires industry to first prove its capabilities to set the scene for further support measures.

The land-based site development is estimated to decrease significantly after a record high in 2017 installations driven by the rush of developers to meet the last subsidy deadlines unless the plans for land-based wind development in the remote islands go forward.

R,D&D ACTIVITIES

National R,D&D Priorities & Budget

Last November, the UK government published its Industrial Strategy: a long-term plan to boost the productivity and earning power in the UK. R&D investment in the public and private sector is placed at the core of this new strategy. Among the policies mentioned, the UK aspires to:

- Raise the total R&D investment to 2.4% of GDP by 2027
- Increase the rate of R&D tax credit to 12%
- Invest 725 million GBP (816 million EUR; 979 million USD) in new Industrial Strategy Challenge Fund programs to capture the value of innovation [14]

An extra 2.3 billion GBP (2.6 billion EUR; 3.1 billion USD) of public funding will be added into R&D in 2021-2022, raising government spending to 12.5 billion GBP (14.1 billion EUR; 16.9 billion USD). The government will also work with industry to encourage private spending, which could lead to an increase of 80 billion GBP (90 billion EUR; 108 billion USD) over the next ten years and spread available funding across UK to eliminate regional concentration, especially in southeast [14].

The Industrial Strategy also includes the launch of Sector Deals, partnerships between government and industry aiming to increase sector productivity. The first Sector Deals are in life sciences, construction, AI, and the automotive sector. The UK offshore wind industry submitted a proposal for an offshore wind Sector Deal to the UK government in early 2018 [15].

National Research Initiatives & Results

- **Wind Blade Research Hub** is a 2.3-million GBP (2.6 billion EUR; 3.1 million USD), five-year research partnership between the Offshore Renewable Energy Catapult and the University of Bristol. Phase one of the industry-leading program of strategic research and development, which will investigate blade materials and manufacturing technology, blade integrity, blade design and performance, is currently underway. The first project initiated under the Research Hub has been completed with a successful outcome and will now be extended into a PhD.

- **The Offshore Wind Innovation Hub** is a coordinating body funded by BEIS and jointly delivered by ORE Catapult and Innovate UK's Knowledge Transfer Network. Since 2017, the Hub has been working with stakeholders from across the offshore wind sector to develop a series of Innovation Roadmaps for UK Offshore Wind. A significant milestone was met in the last quarter, with four technology roadmaps being published on turbines, O&M and wind farm lifecycle, electrical infrastructure, and sub-structures.

- **The Supergen Wind program** launched its fourth round of flexible funding in 2017 and awarded grants to two floating wind projects: one on structural design and integrity enhancement of offshore floating support structures, and one on stochastic methods and tools to support "real-time" planning of risk-based inspection for offshore wind structures. A general assembly meeting in November presented results from ongoing Supergen Wind research to 80 attendees from industry and academia.

Test Facilities & Demonstration Projects

- **Statoil** installed the world's first floating, grid-connected offshore wind park, the 30-MW Hywind, offshore pilot wind park, which achieved 65% capacity factor from November 2017 through January 2018 [17].

- **The Blade Erosion Test Rig (BETR) facility** commissioned and has been fully operating with both commercial and research tests from September. The facility offers testing for a range of customers from the wind and aerospace sectors, including SMEs, blade repair companies, and large multi-national coating and polymer companies.

- **FSFOUND**: ORE Catapult is partnering with EDF and Royal Bam Group on an innovative Float and Sink (self-installing) Gravity Based Foundation to reduce the LCOE. EDF has completed installation of all five wind turbine generators at the Blyth Offshore Demonstration site. ORE Catapult incorporated a condition monitoring system into gravity-based foundations. Data from sensors installed prior to deployment will be analyzed in the next few months.

Collaborative Research

Offshore Renewable Energy (ORE) Catapult is partnering with academic organizations, industry companies and certification bodies in the Lifes50+ project on to develop a methodology for evaluating and qualifying floating wind substructures in water depths greater than 50 m. The project aims to progress two designs to TRL 5 for 10-MW wind turbines (Figure 2). Phase I evaluation was completed in 2017, during which four floating offshore wind turbines were assessed in terms of cost, risk, life cycle assessment, and technical KPIs, and two designs were chosen to be wave tank and wind tunnel tested.

Some of the UK's most innovative small businesses and universities are set to gain access to China market, following an agreement between the UK's ORE Catapult, China's Tus-Wind and TusPark Newcastle. This international R&D platform will help the two nations work together to advance offshore wind technology co-operation.

The IEA Wind TCP sponsors cooperative research tasks. UK engagement includes:

- Task 11 Base Technology Exchange
- Task 26 Cost of Wind Energy
- Task 30 Offshore Code Comparison Collaboration Continued, with Correlation (DNV assumes UK costs)
- Task 32 Wind Lidar Systems for Wind Energy Deployment
- Task 36 Forecasting for Wind Energy (Met Office assumes UK costs)
- Task 37 Wind Energy Systems Engineering: Integrated Research, Design & Development

Figure 2. SINTEF's team has developed a unique test method called "Real-Time Hybrid Model (ReaTHM®)" as part of the LIFES50+ project (Source: Lifes50plus.eu) [16]

IMPACT OF WIND ENERGY

Environmental Impact

The UK was the only country in the EU to reduce its electricity consumption last year (-1.8%), while the average EU power use grew by 0.7% [19]. With more than 40 GW of renewable energy capacity installed in the UK, 2017 was declared the greenest year ever [20]. All renewable energy sources contributed 29.4% to the total amount of electricity generated in the UK. The annual average share of wind energy was 50% of the renewable electricity generated and topped up to 61% in the last quarter of 2017 [1].

The emissions savings attributed to wind energy are estimated at approximately 5.8 million tonnes of CO_2 per annum. British wind farms generated more electricity than coal plants on more than 75% of days this year [20].

Economic Benefits & Industry Development

The level of UK-based content continues its upward trend in the wind energy sector. UK turnover and employment in both the land-based and offshore wind sectors grew in 2016; combined, they accounted for 6.3 billion GBP (7.1 billion EUR; 8.6 billion USD) of turnover and 14,000 employees [21]. Additionally, the UK's export opportunities are growing, as the UK expertise is highly valued overseas with the US, China, and other European markets being targeted markets.

The *Offshore Wind Industry Investment 2017* report by RenewableUK showed the UK content of offshore wind farms has risen by 5% and now stands at 48%, covering stages of development, construction and operation of the project lifecycle [22]. This year, UK offshore wind will get a Sector Deal—a partnership between government and industry that is anticipated to boost productivity, employment, innovation and skills—as part of the government's industrial strategy [23].

One example of the continuous investment activity is MHI Vestas' plans to convert a decommissioned, oil-fired power plant in Fawley into a painting and logistics facility for its 80-meter turbine blades (Figure 3) [18]. The new facility is part of the company's UK industrialization strategy and is expected to create up to 50 jobs complimenting the existing manufacturing facility on the Isle of Wight.

Ørsted has signed a contract with Bladt Industries for 96 transition pieces for its Hornsea Project One offshore windfarm, of which 56 will be made at the Offshore Structures Britain (OSB) facility in Haverton Hill, safeguarding around 200 jobs [24].

Figure 3. MHI Vestas expansion plans for new blade painting and logistics facility in Fawley (Source: MHI Vestas Offshore) [18]

NEXT TERM

The UK's industrial strategy is targeting robotics and AI, which will have significant applications to land-based and offshore wind O&M.

- The UK government has announced a new 28 million GBP (32 million EUR; 38 million USD) fund and plans to encourage progress in smart systems, industrial energy reduction, and offshore wind [25].
- An 84 million GBP (95 million EUR; 113 million USD) fund to support robotics technology R&D of smart energy systems includes plans for four new research hubs, aiming to develop robotics for nuclear and offshore wind. More than 68 million GBP (77 million EUR; 92 million USD) of investment is directed toward robotics and AI projects to improve safety in extreme environments through the Industrial Strategy Challenge Fund. The remaining 16 million GBP (18 million EUR; 22 million USD) is directed toward smart energy systems innovation [26].

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United States

Table 1. Key Statistics 2017, U.S.		
Total (net) installed wind power capacity		88,973 MW
Total offshore capacity		30 MW
New wind power capacity installed		7,017 MW
Decommissioned capacity (in 2017)		43 MW
Total electrical energy output from wind		254 TWh
Wind-generated electricity as percent of national electricity demand		6.3%
Average national capacity factor		32.6%
National wind energy R&D budget		90 mil USD; 75 mil EUR
Target	Land-based: Reduce LCOE for utility-scale to 0.031 USD/kWh (0.026 EUR/kWh) without incentives by 2030 Offshore: Reduce LCOE of fixed-bottom to 0.93 USD/kWh (0.78 EUR/kWh) by 2030 [2]	

OVERVIEW

In 2017, federal and state policies, market demand, and falling costs drove wind industry growth in the United States. Research and development supported cost reductions and technology advancements and addressed market barriers. As a result, the U.S. wind industry added 7,017 megawatts (MW), and cumulative utility-scale capacity grew to 88,973 MW across 41 states and two territories. This represents 16% of global wind power capacity and enough electricity to power 24 million American homes [1]. Wind now supplies 6.3% of the country's electricity demand. The U.S. Department of Energy's (DOE's) *Wind Vision* scenario found it feasible for wind to supply 10% of national electricity demand by 2020 [2].

Iowa, Kansas, South Dakota, and Oklahoma meet 30% of their electricity needs with wind energy and 14 states meet at least 10% of their electricity needs with wind. Traditional utilities and commercial and industrial customers demonstrated strong demand for power purchase agreements, contributing to the nearly 5,500 MW of new wind agreements signed in 2017 [1].

The federal production tax credit and state-level renewable portfolio standards (RPSs) continued to drive the market [1, 3, 4]. Wind power capacity under construction (13,332 MW) or in advanced development (15,336 MW) increased by 34% [1]. At the end of 2017, there were 14 proposed offshore wind projects spanning 10 states and representing over 12,500 MW of potential offshore wind power capacity [1].

MARKET DEVELOPMENT

National Targets & Policies Supporting Development

In the *Wind Vision* report, DOE analyzed a scenario finding it feasible for wind to supply 10% of national electricity demand by 2020, 20% by 2030, and 35% by 2050 [2]. DOE seeks cost reductions in the levelized cost of electricity (LCOE) from utility-scale, land-based wind to 0.052 USD/kWh (0.043 EUR/kWh), without incentives, by 2020, and to 0.031 USD/kWh (0.026 EUR/kWh) by 2030. Similarly, fixed-bottom, offshore wind power cost reduction goals are to achieve 0.149 USD/kWh (0.12 EUR/kWh) by 2020 and 0.093 USD/kWh (0.078 EUR/kWh) by 2030 [5].

DOE, through its Wind Energy Technologies Office, and the U.S. Department of the Interior, through its Bureau of Ocean Energy Management, jointly produced an updated national strategy to facilitate the responsible development of U.S. offshore wind energy. The strategy includes reducing costs and technical risks, supporting stewardship of U.S. waters, and increasing understanding of the benefits and costs of offshore wind energy.

DOE's Atmosphere to Electrons (A2e) initiative found that, if research objectives are met, unsubsidized wind energy costs could be reduced by up to 50% by 2030, assuming a 46 USD/megawatt-hour (MWh) baseline derived from the 2015 average of national installed utility-scale wind [6].

Twenty-nine states, the District of Columbia, and three territories have enacted RPSs. Nationally, wind power capacity accounted for 61% of capacity additions to meet these RPS goals into mid-2017. The American Wind Energy Association estimated that RPS policies will drive 15.5 gigawatts (GW) of new wind power capacity from 2017 through 2025 [4].

Progress & Operational Details

Policy, demand, wind resources, and infrastructure drove state-level wind power gains in 2017. Nearly all (91%) newly-installed wind power capacity occurred in the Midwest (30%), Plains (21%), Mountain West (20%), and Texas (20%). Texas continued to lead all states in wind power capacity additions (2,305 MW) and cumulative installed capacity (22,599 MW). Oklahoma surpassed Iowa to become the second-ranked state in the nation, with wind power capacity additions of 851 MW and cumulative installed capacity of 7,495 MW, thanks to Oklahoma's abundant wind resources, five-year property tax exemption for wind farm sites and, until its July 2017 expiration, a tax credit for zero-emission electricity production.

In third place, Iowa had 7,308 MW of cumulative installed capacity and 397 MW in capacity additions. California ranked fourth with 5,555 MW of cumulative installed capacity and 50 MW in capacity additions, and Kansas ranked fifth with 5,110 MW of installed capacity and 659 MW of capacity additions.

Every major region of the country had wind projects under construction or in advanced development at the end of 2017, amounting to 28 GW. Texas led in this category as well, with 3,462 MW under construction or in advanced development, followed by Wyoming (3,000 MW), Oklahoma (1,366 MW), and New México (980 MW). Wyoming's leap resulted from construction beginning on the 1,000-turbine Chokecherry and Sierra Madre Wind Energy Project.

Four original equipment manufacturers captured 99% of the U.S. turbine manufacturing market in 2017, which continues to consolidate: Vestas (35.4%), GE Renewable Energy (29.4%), Siemens Gamesa Renewable Energy (23.2%), and Nordex USA (11.5%) [1].

Matters Affecting Growth & Work to Remove Barriers

Several activities addressed potential barriers affecting U.S. wind power growth (cost and efficiency, siting/permitting, environmental/aesthetic impacts, and transmission capacity).

- DOE's WINDExchange stakeholder engagement effort helps address siting and development concerns around the deployment of wind energy by providing fact-based information to consumers and decision makers. The program's six Regional Resource Centers work with local stakeholders to facilitate local planning and decision making affecting market acceleration and deployment [7].
- DOE's Competitiveness Improvement Project sought cost and efficiency improvements for small- and medium-sized turbines for distributed wind power in partnership with industry [8].
- Innovation continued on floating offshore wind platforms for deep-water sites [9].
- Idaho National Laboratory devised the GLASS tool to achieve dynamic line ratings for transmission lines, enabling higher transmission capacity under specific conditions [10].
- DOE's Wind Energy Technologies Office collaborated with the Department of Defense, Federal Aviation Administration, and National Oceanic and Atmospheric Administration (NOAA) to establish the Wind Turbine Radar Interference Mitigation Working Group to reduce wind turbine interference with radar systems involved in air traffic control, weather forecasting, homeland security, and national defense missions [11].

R,D&D ACTIVITIES

National R,D&D Priorities & Budget

In 2017, DOE's Wind Energy Technologies Office focused on enabling and accelerating widespread deployment of clean, affordable, and reliable wind power in the United States. This office promotes national security, economic growth, and environmental quality through technology R&D, testing and demonstration, and deployment efforts.

Activities during 2017 targeted wind turbine design, reliability, wind plant optimization, cost reduction, and mitigation of environmental impacts and deployment barriers, including grid integration. R&D on taller towers, larger rotors, and increased energy capture aimed to broaden the number of available sites for economic wind deployment.

Congress allocated 90 million USD (75.0 million EUR) to DOE in fiscal year 2017 for wind energy research [12]. DOE also announced 18.5 million (15.4 million EUR) for an offshore wind R&D consortium to target offshore wind power cost reductions [13].

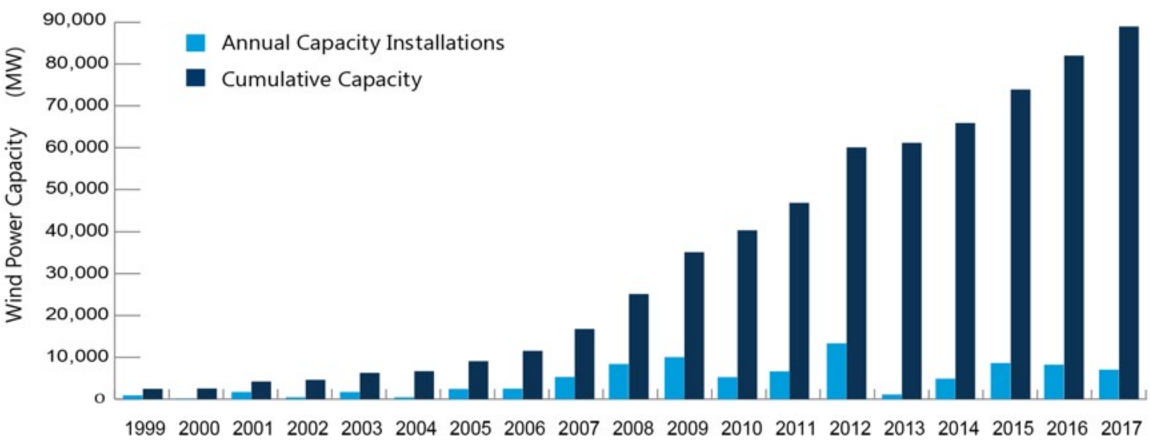

Figure 1. U.S. annual and cumulative utility-scale wind power capacity (Source: AWEA 2017 Annual Report)

National Research Initiatives & Results

Wind plant optimization research conducted through the A2e initiative sought to understand the wind plant operating environment through systems-level research and high-fidelity modeling [6]. Some of this work is supported by the Exascale Computing Project, which focuses on achieving 10^{18} operations per second to accelerate predictive wind flow modeling and ultimately lower costs, optimize plant performance, and improve U.S. competitiveness [15]. A 2017 National Renewable Energy Laboratory (NREL) report found that scientific advances enabled by A2e research could cut the unsubsidized cost of wind energy in half, allowing wind to supply 20% of the United States' energy needs by 2030 and 47% of total U.S. energy needs by 2050 [14].

To improve the accuracy of forecasting models and thereby increase wind energy production, researchers from DOE's Wind Forecast Improvement Project studied the effect of different variables—such as speed, direction, shear, duration, and time and spatial scales of a wind power plant—on wind speed and wind power forecasts at turbine hub heights [16].

To remove siting barriers for wind energy projects, Sandia National Laboratories partnered with NOAA to develop a geographic information system to aid officials in evaluating the potential impacts of wind turbines on radar systems, including weather forecasts and NOAA's severe weather warning system [17].

DOE's Small Business Vouchers program awarded funding to three startups in 2017 so they could focus on ways to maximize blade life, build taller wind towers, and optimize wind plant performance and lifespan [18].

Test Facilities & Demonstration Projects

Wind laboratory and testing facilities supported by DOE allow wind technology companies and inventors to validate and commercialize their technologies. These testing facilities, which span the country and offer unique capabilities, are detailed in the *Wind Energy Facilities Book*, published in 2017 [19].

DOE supported two Offshore Wind Advanced Technology Demonstration Projects. The Lake Erie Energy Development Corporation's Icebreaker Project plans to install six 3.45-MW, direct-drive turbines on mono bucket foundations eight miles off the coast of Cleveland in Lake Erie. The University of Maine completed the scoping process for its New England Aqua Ventus I project, which is planned as a pilot, floating offshore wind farm with two 6-MW direct-drive turbines on concrete, semisubmersible foundations in deep waters off Monhegan Island, Maine, where bottom-fixed foundations are not feasible [20].

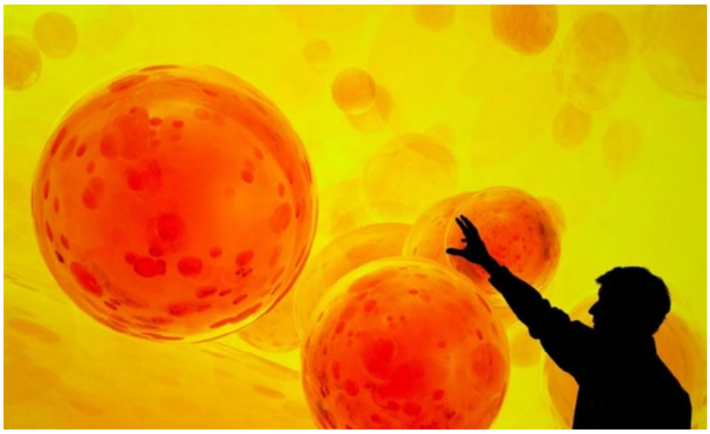

Figure 2. Sandia National Laboratories' Advanced Simulation and Computing program offers computing capabilities that help the wind industry achieve overall wind energy cost reductions and increased turbine performance (Photo courtesy of Sandia National Laboratories)

Collaborative Research

U.S. representatives participated in research for 14 of the International Energy Agency (IEA) Wind TCP tasks in 2017. U.S. wind energy stakeholders collaborated with many domestic departments and agencies, and engaged with international stakeholders through IEA Wind TCP, the International Electrotechnical Commission, and other partnerships.

Research conducted through U.S. interagency and international coordination includes radar mitigation, wind power plant optimization, technology transfer, market barrier mitigation, and grid integration. For example, NREL researchers led more than 30 countries and institutions to validate offshore wind models by comparing physical test data from offshore wind-energy systems against the simulated data produced by modeling tools to develop more cost-effective designs for semisubmersible platforms at deep-water sites. The Offshore Code Comparison Collaboration, Continued, with Correlation project, conducted under the IEA Wind TCP Research Task 30, will help the United States and other countries make use of significant wind resources in deep-water installations, which comprise roughly 60% of U.S. wind resources [21].

IMPACT OF WIND ENERGY

Environmental Impact

Wind energy reduces the emission of air pollutants that contribute to global environmental impacts and human respiratory disease. In 2017, 254 million MWh of wind energy displaced an estimated 189 million metric tons of carbon dioxide, reducing U.S. electricity sector emissions by 11%. Wind production also displaced approximately 188,000 metric tons of sulfur dioxide and 122,000 metric tons of nitrogen oxides. Wind power also saved approximately 95 billion gallons of water that would otherwise have been used to cool thermal power plants [1].

Ongoing DOE funding of R,D&D to minimize wind power impacts on wildlife supported multiple projects with stakeholders across at least 14 states [22]. These projects included tests off the Maine coast to improve the accuracy of ThermalTracker, an open-source software developed by the Pacific Northwest National Laboratory, which quantifies the flight tracks of birds and bats [23]. The automated Eagle Take Minimization System, tested in New York and New Hampshire, combines radar, cameras, and a turbine's computers to detect eagles in time to turn off turbines [20].

Economic Benefits & Industry Development

U.S. wind power produced an annual economic domestic benefit of about 20 billion USD (16.7 billion EUR) in 2016, the last year assessed [24]. The 7,017 MW installed in 2017 represented about 11 billion USD (9.2 billion EUR) invested. The domestic wind energy industry supported 107,444 workers—a 6% increase over 2016 [25]. The U.S. Bureau of Labor Statistics reported that wind turbine technician is the second-fastest growing job in the country, behind solar panel installers. Turbine technician jobs are forecast to grow more than 96% over the coming decade [26].

Currently, all 50 states have wind-related jobs. The top four states, ranked by number of wind-related jobs, are: Texas (24,000), Oklahoma (8,000), Iowa (7,000), and Colorado (5,000). More than 99% of the U.S. wind power fleet is located in rural areas and 81% of these are in low-income counties. Landowners in these areas received 267 million USD (223 million EUR) in land-lease payments.

In 2017, the wind power industry installed 3,022 utility-scale turbines, bringing the nation's total to 54,000 turbines [1]. Further, 3,269 small (100 kilowatts or smaller) turbines were added, bringing the cumulative to more than 81,000 wind turbines in distributed applications. [27].

Power purchase agreements or qualifying facility contracts accounted for 5,496 MW, or 62%, of 2017's new installed capacity. Utilities represented 63% and corporations and other nonutility purchasers represented 37% [1].

NEXT TERM

The U.S. wind energy development pipeline remains strong, with 28 GW in projects under construction or in advanced development at the end of 2017. In addition, the four-year window for beginning production-tax-credit-supported projects is expected to drive construction through 2023 [1]. Forecasts project U.S. wind energy growth of 8–10 GW/year through 2020, for a total of 35 GW added 2017–2020, and 248,000 wind-related jobs and economic impact of 24 billion USD (20 billion EUR) in 2020 [24]. An NREL report found that continued investment in wind R&D could achieve costs competitive with the fuel-only cost of natural-gas-fired electricity generation in less than 15 years [14].

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Opening Photo: Wind turbines on Kodiak Island, Alaska. (Photo by Dennis Schroeder, NREL)

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Appendix A
IEA WIND TCP EXECUTIVE COMMITTEE 2017

These are the members who served The IEA Wind TCP Executive Committee in 2017. 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 B
CURRENCY CONVERSION RATES

Country	Currency	1 EUR	1 USD
Austria	EUR	1.000	1.200
Belgium	EUR	1.000	1.200
Canada	CAD	0.663	0.795
China	CNY	0.128	0.154
Denmark	DKK	0.134	0.161
Finland	EUR	1.000	1.200
France	EUR	1.000	1.200
Germany	EUR	1.000	1.200
Greece	EUR	1.000	1.200
Ireland	EUR	1.000	1.200
Italy	EUR	1.000	1.200
Japan	JPY	0.007	0.009
Korea	KRW	0.001	0.001
México	MXP	0.042	0.051
Netherlands	EUR	1.000	1.200
Norway	NOK	0.102	0.122
Portugal	EUR	1.000	1.200
Spain	EUR	1.000	1.200
Sweden	SEK	0.102	0.122
Switzerland	CHF	0.855	1.026
United Kingdom	GBP	1.125	1.350
United States	USD	0.833	1.000

Source: Federal Reserve Bank of New York (www.x-rates.com) 31-Dec-17

Appendix C
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.

FTE: full-time equivalent

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

N/A: not applicable (or not available)

NGO: non-governmental organizations

OA: operating agent that manages the work of a research task

OEM: original equipment manufacturer

O&M: operations and maintenance

Penetration rate: the share of total wind generation relative to total end-use energy demand, expressed as a percentage

PJ: peta joule

PPA: power purchase agreement

PSO: public service obligation

PV: photovoltaics or solar electric cells

R&D: research and development

R,D&D: research, development, and deployment

RE: renewable energy

RES: renewable energy systems (or sources)

Repowering: taking down old turbines at a site and installing newer ones with more generating capacity

RO (renewables obligation rotor): the blades attached to the hub

RPS: renewables portfolio standard

SCADA: supervisory control and data acquisition

Semi-offshore projects: projects in the tidal zone or in very shallow water

SME: small- and medium-sized enterprises

Specific power: the ratio of generator nameplate capacity (in watts) to the rotor-swept area (in m2)

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

Appendix D
CONTRACTING PARTIES AND THE EXECUTIVE COMMITTEE

OVERVIEW

The Implementing Agreement for Co-operation in the Research, Development, and Deployment ofWind 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 A) 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 the IEA Wind TCP in 2017

Country/Sponsor	Contracting Party
Austria	The Republic of Austria
Belgium	Government of Belgium
Canada	Natural Resources Canada
CWEA	Chinese Wind Energy Association (CWEA)
Denmark	Danish Energy Authority
European Commission	European Commission
FInland	BusinessFinland (formerly 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	New Energy and Industrial Technology Development (NEDO)
Korea	Government of Korea
México	Centro Mexicano de Innovacion en Energfa Eolica (CEMIE Eolico)
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	WindEurope

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 2017, Igancio Marti (Denmark) 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 2018. Jose Manuel Franco-Nava (México) was also elected to serve as a vice chair starting in 2018.

Table 2. Active IEA Wind TCP Research Tasks

Task No.	Task Name	Operating Agent	No. of Participating Countries in 2017
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 (2012-2017)	7
28	Social Acceptance of Wind Energy Projects	ENCO Energie-Consulting AG, Switzerland (2007-2011; 2012¬2015); IPC, Ireland (2016-2019)	8
29	Analysis of Wind Tunnel Measurements and Improvement Aerodynamic Models	TNO, the Netherlands (2012-2014; 2015-2017)	9
30	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)	10
32	Wind Lidar Systems for Wind Energy Deployment	ForWind Centre for Wind Energy Research, Germany (2012-2015); Stuttgart Wind Energy (SWE), Germany (2016-2018)	12
34	Working Together to Resolve Environmental Effects of Wind Energy (WREN)	NREL, the United States (2013-2016; 2016-2019)	11
35	Full-Size Ground Testing of Wind Turbines and Components	Aachen University RWTH, Germany (2013-2017)	5
36	Forecasting for Wind Energy	DTU Wind Energy, Ris0, Denmark (2015-2018)	13
37	Wind Energy Systems Engineering: Integrated Research, Design, and Development	NREL, the United States (2015-2018)	8
39	Quiet Wind Turbine Technologies	Sustainable Energy Authority of Ireland (SEAI), Ireland and Ion Acoustics, United Kingdom (2018-2020)	1
40	Downwind Turbine Technologies	Kushyu University, Japan and Wind Energy Institute of Tokyo, Japan (2018-2020)	2

Participants
In 2017, there were several personnel changes among the members and alternate members representing their organizations (See Appendix A: IEA Wind TCP Executive Committee 2017). For the latest and most complete ExCo member contact information, visit community.ieawind.org. The contracting party for Japan changed to the New Energy and Industrial Technology Development Organization (NEDO). 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 2017 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 79th ExCo meeting was hosted by VTT Technical Research Center of Finland. The meeting was held in Espoo, Finland, from May 30–June 2, 2017. The 41 participants included ExCo members or alternates from 18 participating countries and sponsor members and observers from Japan, South Africa, and the United States. Presentations were given about all 15 active research tasks. The Common Fund audit report for 2016 was approved. The The meeting included a technical tour of the ABB Oy Factory, a manufacturer of generators and converter systems for wind turbines.

The 80th ExCo meeting was hosted by the Centro Mexicano de Innovación en Energía Eólica (CEMIE Eólico). The meeting was held in Huatulco, México, on November 13–16, 2017. The 28 participants included ExCo Members or Alternates from 14 participating countries and sponsors; observers from México and the United States also participated. The Common Fund budget for 2018 was approved. The hosts sponsored technical tour to Instituto Nacional de Electricidad y Energías Limpias (INEEL) Regional Centre of Wind Technology (CERTE) in Juchitan, Oaxaca.

Decisions, Publications, and Outreach
In 2017, the IEA Wind TCP ExCo approved one new research task, Task 40 Downwind Turbine Technologies, which will formally begin in 2018. Task 35 Full-Size Ground Testing of Wind Turbines and Components concluded at the end of 2017 and the final technical report is expected in 2018.

The ExCo approved extending Task 25 Grid Integration and Task 29 Aerodynamics for new three-year terms, as well as short-term extension with no additional for Task 30 OC5 to complete Task reporting activities.

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 Renewable Energy Working Party (REWP) meetings in March and October 2017.

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 2016 Annual Report* was published in September 2017 and 1,000 copies of the 2017 Overview (executive summary and task chapters) were printed and distributed to member organizations. Press releases were issued with links to the electronic version on the IEA Wind TCP website.

This, the 40th IEA Wind TCP annual report, lists accomplishments by the close of 2017. The IEA Wind TCP 2017 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 17 provide additional information on each task. Member country chapters (Chapters 18 through 40) describe activities in the research, development, and deployment of wind energy in each participating country during the year that just ended.

The *IEA Wind TCP 2017 Annual Report* is published by PWT Communications, Inc in Olympia, Washington, United States, on behalf of the IEA Wind TCP 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.

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Front cover: Kayaking in the Pori offshore wind farm in Finland (Source: Hannele Holttinen)

Inside cover: Wind farm in La Ventosa-Juchitán in Oaxaca, México (Photo Courtesy of INEEL, Mexico)

IEA Wind TCP
2017 Annual Report

The IEA Wind Technology Collaboration Programme (TCP) is the leading international organization for wind energy research cooperation. For 40 years, the IEA Wind TCP has been multiplying national technology research, development and deployment (R,D&D) efforts through information exchange and joint research projects. Researchers from 24 member countries and international organizations, representing over 84% of global installed wind capacity, have produced significant research results, design tools, and guidelines for the design and operation of offshore and land-based wind turbines.

There are still significant opportunities for technology innovation to maximize value and continue to improve cost-competitiveness—especially offshore. The IEA Wind TCP fosters collaborative research and the exchange of best practices and data by supporting international expert collaboration and promoting standardization to accelerate the pace of technology development and deployment.

The *IEA Wind TCP 2017 Annual Report* highlights the work of the 16 research Tasks and provides an extensive summary of 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.community.ieawind.org.

iea wind

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